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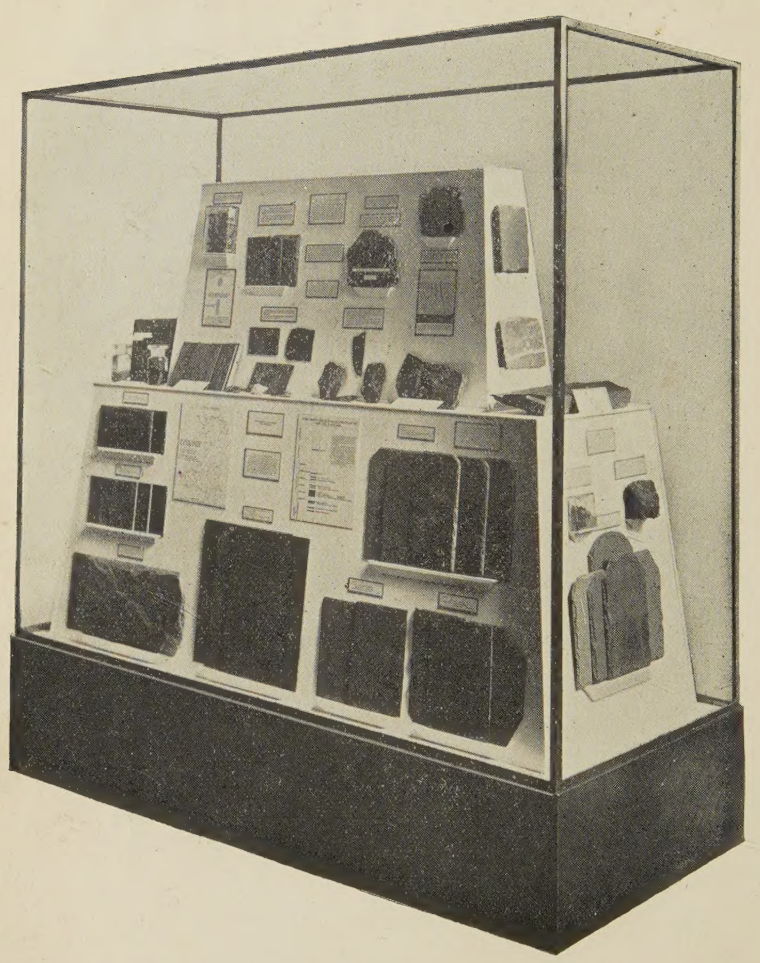

PLATE 1.—An exhibit in the Museum illustrating the slates of Wales.

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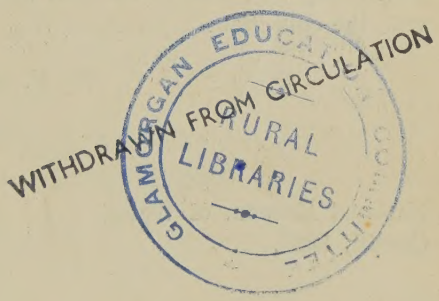
NATIONAL MUSEUM OF WALES

THE SLATES OF WALES

By F. J. NORTH, D.Sc., F.G.S.



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PREFACE

Wales, with about sixty slate-mines and slate-quarries employing more than eight thousand people, produces the best slate in the world, and furnishes over eighty per cent. of the total slate-output of the British Isles. It is fitting, therefore, that the National Museum of Wales should give prominence to exhibits dealing with the nature and origin of slate and its distribution in the Principality. The object of this pamphlet, prepared by the Keeper of Geology in the Museum, is to expand, in the simplest possible language, the information contained in the Museum labels into a form which may be found of use also by those who are unable to visit the collection.

R. E. Mortimer Wheeler,
Director.

National Museum of Wales,
Cardiff, 1925.

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SUMMARY FOR THE USE OF VISITORS

The following paragraphs contain a brief account of the salient features of the slate exhibit in the geological gallery of the Museum.

Slate has been produced by the alteration of a rock like Clay, which is one of the products of the decomposition of rocks by natural agents such as rain-water and the gases dissolved in it.

The nature of the alteration is such that the constituent particles are more closely packed in slate than in clay, and whereas in that rock they are not arranged according to any particular plan, in slate they all lie in the same direction, and overlap after the manner of the scales on a fish.

The result of the alteration is that while clay breaks down into mud when mixed with water, slate is unaffected by it. Dry clay readily crumbles into fragments of irregular shape and size, but slate can be *split* into sheets of almost any desired thickness. This property is known as cleavage.

The cause of the alteration is to be found in the movements which have from time to time taken place in different parts of the earth's crust, compressing the rocks and often resulting in the elevation of mountain ranges.

Slates vary in colour, in the ease with which they may be cleaved, and in the smoothness of the split surfaces : these variations are largely due to differences in the nature of the rocks from the compression of which the slate resulted.

The best commercial slates have been produced where thick beds of clay, fine and uniform in grain, have been subjected to intense lateral compression, when deeply buried beneath other strata which had been deposited upon them before the compressing force commenced to operate.

From these considerations it follows that slate may be expected to occur in regions where mountains of folded rocks exist. It is most frequently, and in Wales exclusively, found among the rocks of the older geological formations, since the older the rock the more likely it is to have been affected by earth movements, and after that to have been exposed at the surface as a result of the wearing away of the strata which once covered it.

In Wales, slates of commercial importance occur in Carnarvonshire, Montgomeryshire, Merionethshire, Denbighshire, and Pembrokeshire.

Fossils which may have been present in the original clay-rock were usually obliterated during the changes which resulted in the formation of slate, but occasionally they have been preserved. Fossils in slate are always flattened and often distorted, bearing witness to the extent to which the original rock has been compressed and deformed.

SLATE

The word " slate " comes to us from the old English " slat " (or sclat) and through it from the old French verb " *esclater*." meaning " to split," or " to shiver to pieces." In a general sense the term slate has been applied to any kind of rock that can be split into sheets, especially if the sheets can be utilized for covering roofs or for other purposes where thin strong slabs of stone are required, but as used in geology the significance of the word is much more restricted.

Strictly speaking, slate is a rock which was once a fine grained sediment like clay or some kinds of volcanic dust, and which, as the result of heat and pressure acting upon it at some time when it was deeply buried beneath the earth's surface, has acquired the property known as " cleavage," that is to say, a tendency to split in a definite direction, into sheets of almost any thickness.

Slaty cleavage, although best exemplified in slate, is not confined to that rock, but may have been developed to a greater or a lesser extent in almost any constituent of the earth's crust that has been subjected to the necessary conditions of heat and pressure.

Many other rocks, such as shale, and certain kinds of sandstone and of limestone are also fissile, that is, capable of being split easily, but the sheets so obtained correspond to the original layers or beds in which the rocks were deposited. Since the splitting in such rocks almost invariably takes place along the junction between any two beds, the thickness of the sheets is determined by that of the original layers, and only on rare occasions are they strong enough to be of any economic value : these fissile rocks which are not true slates will be discussed at a later stage.

In slate, properly so-called, the cleavage or splitting has no relation to the original bedding of the rock, having been produced after the rock was formed. To this category belong nearly all the varieties of slate which are now quarried in Wales.

The origin of slate.—The majority of slates were originally clay, and in order to appreciate the conditions which gave rise to the extensive slate deposits of Wales, it is necessary to consider first the formation of clay.

Clay has been formed in a variety of ways, but most of the thick and widely-spread deposits from which commercially important slates have been formed, represent the finest material

derived from the decomposition or " weathering " of the rocks exposed at the earth's surface, carried along by rivers and deposited upon the floor of the sea.

The weathering of rocks involves their mechanical disintegration, as well as the chemical alteration of some of their constituent minerals. This is because many minerals are decomposed by rain-water charged with gases dissolved during its passage through the atmosphere, giving rise to comparatively soft material that is easily washed away; at the same time the undecomposed or more resistant mineral particles, are no longer held securely together, but are also liable to be blown away or moved by running water.

The decomposition of the surface layers of exposed rocks takes place very slowly, but eventually it results in the formation of loose particles varying greatly in size and in composition; this material, shifted by rain and wind, finds its way into streams, and by them is carried along until it eventually comes to rest on the floor of the sea into which the river flows. The finer material moves along more rapidly and is carried farther than the larger particles, so that there is a tendency for the latter to be deposited near to the land, giving rise to sand, while the finer material settles out farther from the shore, as a deposit of mud.

These processes have been in operation since the condition of the earth permitted the formation of oceans and of rain, but, from time to time, movements in the earth's crust* have caused local changes in the distribution of land and sea. Parts of the sea floor have been raised and converted into dry land areas, and as a result, the sediments which had accumulated at the bottom of the sea became the rocks of a new land, and were, in their turn, subjected to the same agents of destruction and transport that had resulted in their formation, thus giving rise to new deposits elsewhere.

In this way, clays have been formed in various places, and at different periods of the earth's history [9, 10].†

Other natural processes, such as the decomposition of granite by acid-laden vapours originating deep beneath the earth's surface, and the grinding away of rocks during the movement of glaciers, have resulted in the formation of clay, but such deposits are usually too local in distribution, too variable in

* " Earth's crust," and " crust of the earth " are terms which belong to the period when it was supposed that the earth was a mass of molten material surrounded by a thin layer of rock, the result of cooling: but although it is now known that such is not the case, the terms are still used to designate the thin superficial layer of the earth, the composition and structure of which can be directly studied or can be inferred from observations made in natural cliffs or ravines, and in artificial excavations such as railway-cuttings and mines.

† A list of works dealing with slate will be found in the bibliography on pages 56–64, and numbers in square brackets refer to papers which may be consulted by those desiring further information.

texture, or too mixed in composition to have yielded commercially useful slates.

If, in any one area, the distribution of land and sea remains unchanged for a considerable time during which the sea floor slowly subsides, the deposits of clay and sand will increase in thickness until the earlier layers will be deeply buried beneath those which were laid down upon them. When in this situation, they are subject to the high temperature which exists in the deeper parts of the earth's crust, and to pressure due to the weight of the strata resting upon them.

In mud, or a recently formed clay deposit, the individual particles vary in shape and in size ; they enclose between them a considerable amount of space, and they are not arranged in any particular manner (see Fig. 1a). Although, in the aggregate, the spaces may amount to 30 or 40 per cent. of the volume of the rock, individually they are exceedingly small, and it is on this account that clay is practically impervious to water.

The effect on clay of the pressure resulting from its burial beneath the strata subsequently deposited upon it, is to pack the particles more closely together, and all those which are longer in one direction than in another (that is, resembling beans rather than peas) tend to take up new positions with their flatter surfaces more or less horizontal (see Fig. 1b). If that part of the earth's crust were then uplifted, causing the sea floor to become dry land, the wearing-down action of rain and rivers would eventually result in the exposure of the once deeply buried sediments, but instead of soft plastic muds, they would appear as rocks such as mudstone and shale : shale, if the nature of the original deposit was such that the pressure resulted in a tendency to split into thin sheets corresponding to the original bedding of the rock, and clay-rock or mudstone if the new rock has the character of a hardened and indurated clay, but no marked tendency to split along the bedding planes.

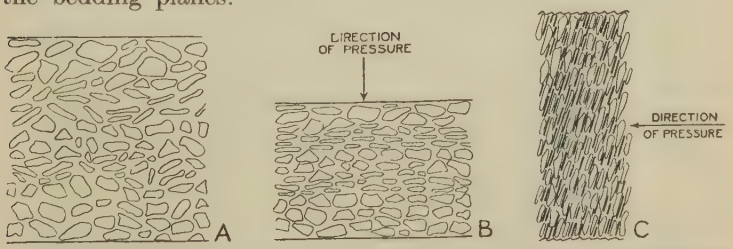

FIGURE 1.—Diagrammatic representation of the arrangement of the particles in (A) clay, (B) shale, and (C) slate.

In shale the particles are more closely packed than in clay, and most of them lie with their longer directions parallel to the surface on which they were deposited ; in slate the particles lie in a direction nearly parallel to that in which the pressure that altered the rock was applied, and flaky crystals of mica have been developed among them.

Both shale and mudstone are common in many parts of Wales : excellent examples of the former, splitting into thin layers like pieces of cardboard, are to be found among the Rhaetic strata of Glamorgan and the older rocks of Pembrokeshire and central Wales. The hard, fissile, clay-rocks associated with coal seams are often (incorrectly) referred to as slate, but they are really shales.

This tendency to split, on the part of shale, is an entirely different thing from the cleavage of slate ; that is only produced when, in addition to being subjected to the pressure due to the weight of the overlying strata, the deeply buried clay deposit is influenced by lateral pressure resulting from movements in the earth's crust.

It is not possible to discuss here the causes of the earth-movements which have resulted in the building of mountain chains and have altered the distribution of land and sea : in a general way they have been dependent upon the cooling and consequent contraction of the earth, but many other factors have also been concerned. That they have occurred, is evident from the frequency with which rocks that must have accumulated as more or less horizontal layers of sediment have been laterally squeezed and thrown into wave-like folds (see Fig. 2). It was lateral pressure of this nature that in certain circumstances caused the transformation of clay into slate.

The change was in part mechanical and in part chemical. As a result of the pressure, the particles of the original clay mass were squeezed more closely together, and in some cases were slightly flattened. Those particles which were longer in one direction than another, or were of a flaky character, were twisted round until they were all arranged in a similar direction, which was more or less transverse to that in which the pressure was being applied (see Fig. 1c).

Eventually, a point was reached when further compression and closer packing of the particles was impossible, and then the clay mass as a whole was compelled to change its shape, becoming, since the pressure was acting more or less horizontally, narrower from side to side and correspondingly thicker from top to bottom. This was accomplished by the particles moving away at right angles to the direction of pressure, a process which would further facilitate an arrangement with their flattest surfaces facing the direction of pressure.

Not only was the material being compressed, but it was subjected to considerable heat : heat due to its depth beneath the surface*, as well as heat generated as a result of the compression.

* At the present time, for as far down as the earth's crust has been pierced and observations made, temperature increases with depth beneath the surface at an average rate of one degree Fahrenheit for every 64 feet.

The combined action of pressure and heat resulted in the constituents of some of the mineral particles entering into new combinations. In particular, very minute flakes or ribbon-like crystals of mica were developed. Mica is a very scaly mineral (large crystals readily split into thin sheets such as are used for lamp chimneys and stove windows), and most of the newly formed mica crystals in the rock that was being turned into slate were also arranged with their flat surfaces facing the direction of pressure—this, because crystals usually tend to grow most freely in directions of least resistance (see Fig. 1c). The mica crystals are very small ; in the best Welsh slates they average about two thousand to the inch in breadth, and six thousand to the inch in thickness.

If the alteration stopped at this point the rock would be a slate, and, on account of the general parallelism of all its particles, original and secondary, it would have a strong tendency to split into parallel-sided sheets.

The overlapping of its component particles, after the manner of the scales of a fish, is responsible for the elasticity of slate. A sheet of shale as large as a postcard and an eighth of an inch thick would break easily if bent, whereas it would be very difficult to snap, with the fingers alone, a sheet of slate of similar dimensions. The remarkable elasticity of the best kinds of Welsh slate was demonstrated at the International Exhibition in 1862, where strips of slate from Blaenau Ffestiniog were exhibited ; they were 10 feet long, 12 inches wide, and only about one sixteenth of an inch in thickness, but could be bent like veneer of wood.

When the condition of slate has been reached, the further operation of the processes described might, if pressure were the predominating factor, result in the bending or crumpling of the cleavage planes, or even in the development of a new cleavage, in addition to, or obliterating the original cleavage. In either case the economic value of the slate is impaired, because a wavy cleavage causes the rock to split with rough instead of smooth faces, and a double cleavage results in the slate breaking into rod-like masses rather than into sheets. Slates of the latter type are sometimes called " pencil slates " on account of the shape of the cleaved fragments ; this does not of necessity mean that they are suitable for making slate pencils, although that is sometimes the case.

Near Shap, in the Lake District, there are certain slates in which a double cleavage causes the rock to break into thin four-sided prisms, from a quarter to half an inch square, and as the rock is soft enough not to scratch ordinary varieties of slate, it was at one time worked for the manufacture of slate pencils [**26**, p. 115].

Other slate pencils were made from soft, poorly cleaved, slabby slates, by carving, first one side of a slab of suitable size and then the other, by means of tools with semicircular notches. This resulted in the formation of sheets of cylindrical pencils, which could easily be broken apart [12, p. 144].

Another effect of extreme pressure is the development of more and larger crystals of mica until the rock becomes first a lustrous mica-slate or "phyllite," and finally a completely crystalline rock of the type known as mica-schist.

When heat is the predominating factor in the alteration of slate, various new minerals develop, forming, at first, small closely-packed dark spots, then definite crystals such as those of the mineral chiastolite. Extreme alteration results, as in the previous case, in a completely crystalline rock.* Alteration of this type occurs where a slate mass has been invaded by a large volume of igneous rock,† which, being intensely hot, has baked the surrounding strata. Slates altered by heat are well displayed in the neighbourhood of the granite of Skiddaw in the Lake District [7] and around the granite masses of Devon and Cornwall.

In Wales, most of the igneous rocks which have been intruded among slates occur as wall-like "dykes" or sheet-like "sills," a few inches or a few yards in thickness: these, compared with intrusions of granite many miles across, are very small, and the heat which they liberated did not profoundly change the surrounding slate, which usually has only been hardened, and slightly changed in colour with or without the development of spots.

In the case of the Cambrian slates of Carnarvonshire, the alteration resulting from the intrusion of igneous material appears to have improved the quality of the slate, except immediately adjacent to the dykes, because two of the largest quarries (Dinorwic and Penrhyn) are situated in the two regions where dykes in the Cambrian rocks are most abundant.

Good examples of slate altered to the stage where they exhibit spots (spotted slate or "spilosite"), are to be seen in the neighbourhood of Tremadoc, where large sheet-like "sills" of igneous rock have been forced among strata of Ordovician

* Names such as mica-slate, chiastolite-slate and hornblende-slate, are given to the varieties of altered slates in which those minerals are especially well developed; the ordinary variety which yields the best roofing slates is known as clay-slate.

† Igneous rocks are those which were originally molten, and either cooled in large masses at great depths beneath the earth's surface (for example, granite) or when molten, were injected as sheets or wall-like masses into pre-existing rocks (intrusive rocks), or reached the earth's surface through fissures in its crust, and flowed from volcanoes (extrusive rocks). The intrusive rocks include many of the igneous rocks of Wales which were formerly called "greenstone," a term still conveniently used where accurate nomenclature is not necessary, and the extrusive rocks include lavas such as those of Conway and Snowdon.

age, destroying the cleavage and developing spots, which microscopic investigation suggests are, in this case, due to the presence of minute scales of the mineral, chlorite [48, p. 218].

Similar spotted slates occur around the "granite" mass forming the hill Moel Tan-y-grisiau, near Blaenau Ffestiniog [63, p. 369], and near the igneous rocks intruded among the slates of the Prescelly district of Pembrokeshire.

The heat which caused the development of spotted slate usually hardened the rock and impaired its cleavage: sometimes it has resulted in the formation of a hard, structureless, splintery rock (adinole). Altered slates of this type occur in many parts of North Wales, as for example near Craig-y-gesail, Tremadoc [48, p. 219], and around Llyn Llagi and Llyn Adar, two small lakes between three and four miles east of Beddgelert [47 p. 125]; they were formerly quarried in various parts of Carnarvonshire for use as hone-stones or oil-stones. "Welsh-oilstone," from near Llyn Idwal and other parts of the Snowdonian area, is very hard and close in texture, and has been found especially suitable for grinding small articles such as lancets.

The characters of the altered rock will depend partly upon its original composition and partly upon the extent to which it has been heated. In the case of the Skiddaw slates already mentioned, it is possible to examine the passage from the unaltered slate at a distance from the granite into the intensely altered rock in contact with it. The slates first exhibit spots, then crystals appear, and finally it becomes completely crystalline [7].

In the case of smaller igneous masses such as those near Tremadoc, the heat liberated was only sufficient to cause the first stage of the alteration.*

It thus transpires that slate is the product at one stage in a series of processes whereby a sedimentary rock, like clay, is converted into a crystalline rock, like schist. This change is known as "metamorphism."

A simple experiment will serve to illustrate, in a general way, the cleavability of slate. A bag nearly full of small bone counters, like those used in certain games, may be taken as representing a mass of clay with its particles arranged according to no particular plan. If the bag were held against the wall and a rolling pressure applied to it by means of a flat piece

* Dykes or Sills of igneous rock may also have been intruded into mudstones or shales before the forces which developed cleavage commenced to operate. In such cases the rock adjacent to the intruded material was usually hardened to such an extent that it more or less completely resisted deformation and cleavage: if, however, very intense pressure prevailed, the igneous rock itself may also exhibit an ill-defined cleavage.

of wood, nearly all the counters would eventually come to lie in the same direction.

Before the application of pressure it would have been difficult to pass a knife through the mass of counters, because it would either have to cut some of them, or else follow an irregular course between them, but after the pressure had been applied, the knife could be passed with comparative ease from one end of the bag to the other in the same direction as the counters were lying, that is, at right angles to the direction in which the pressure was applied. It has already been shown that the conversion of clay into slate involves more than the mere rotation of the rock's constituent particles, and this analogy of the bone counters must not be regarded as illustrating the complete process.

The extent to which cleaved rocks have been compressed is sometimes illustrated when a band, differing in composition or in colour from the main mass, can be examined on a surface at right angles to the direction of cleavage. Such an instance is illustrated in Fig. 2, where it will be seen that the distinctive layer has been bent into folds, which trend parallel to the direction of pressure.

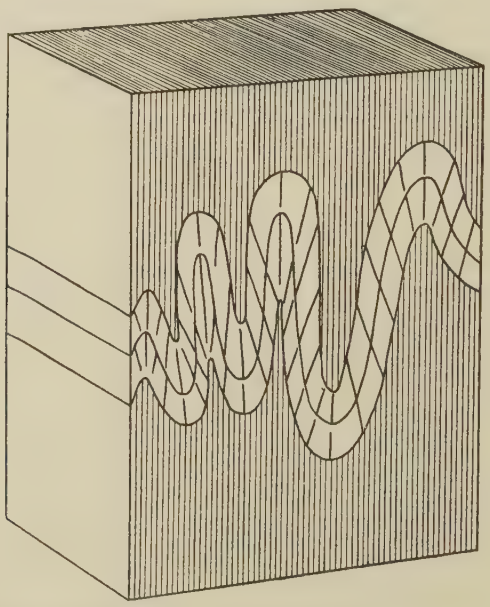

FIGURE 2.—Diagrammatic representation of a block of slate containing a thin bed of sandy rock.

The result of compression is seen in the development of regular cleavage in the fine-grained clay-like sediment, and of folding and indifferent cleavage in the harder bed.

The compression to which slate has been subjected accounts for its density : bulk for bulk, slate is heavier than most sedimentary rocks. The average specific gravity (that is, the weight compared with the weight of an equal bulk of water,) of slate, is 2.86 ; of clay, 2.57 ; of limestone, 2.46 ; and of sandstone, 2.36. The comparison may also be made by considering the weight of equal volumes of each kind of stone ; the average weight of a cubic foot of slate is 178 lbs. ; of clay, 168 lbs. ; of limestone, 153 lbs. ; and of sandstone, 147 lbs.

Slate formed from materials other than clay.—Although the majority of slates have resulted from the alteration of clay deposits, any other material of suitable composition and texture would, if subjected to the same stresses, be converted into slate.

An interesting example of this, is the occurrence, in the Borrowdale area of the Lake District, of slates which were originally fine grained volcanic ashes ejected during explosive outbursts from volcanoes which existed during Ordovician times. Some of the material was very fine dust, and it now cleaves into smooth slates exhibiting varying shades of green ; beds in which large particles (scoriae or ashes) were present, have given rise to coarse slates, mottled in colour, and rough on the cleaved surface [13, 38]. These slates have been extensively used for roofing purposes, but on the whole they yield thicker, and therefore heavier, roof-tiles than the best kinds of Welsh slate. It is probable that the original material of some of the light coloured slates in the Prescelly district of Pembrokeshire [101], and also of those at Blaenau Ffestiniog, was exceedingly fine volcanic dust which accumulated on the sea floor [11].

The growth of knowledge concerning slate.—It is only within the last 90 years that the essential characters of slaty cleavage have been understood, although as far back as the latter half of the eighteenth century two continental geologists (G. Lasius and J. K. W. Voigt), each working in different areas, recognised that cleavage was independent of the bedding of the rocks, but neither offered any explanation of the phenomenon [39a, p. 357].

During the next forty years very few writers referred to the matter, and those who did, contributed little that was of value ; for example, Bakewell (1815) wrote :—" the slaty and tabular structure are, I conceive, the effects of crystallisation, depending on the nature of its constituent parts," but he makes no attempt to explain what he meant by " crystallisation," or to account for its development [16, p. 86].

The earliest reference to the distinction between bedding and cleavage, based upon observations made in this country, is to be found in a discussion of the slaty rocks of the Lake district in " A Concise Description of the English Lakes " (1823) by Johnathan Otley. He wrote :—" the cleavage or bate of the slate . . . is to be found in various degrees of inclination both with respect to the horizon, and the planes of stratification" [17, p. 162].

At about the same time, William Smith, the pioneer in the making of geological maps, also recognised that cleavage and stratification were distinct, and he regarded the former as a kind of crystallisation running in different beds [22, p. 99].

Soon after 1830, Adam Sedgwick of Cambridge began to study the rocks of north and central Wales, and he also recognised that cleavage was independent of the bedding of the rocks and of the folds into which they had been thrown, and further, that it was not merely a variety of the " jointing," to which practically all rocks are subject.

He thought, however, that the tendency which, in crystals, causes each particle to arrange itself in a definite direction, was present also in large rock masses, and suggested that the cleavage of slate is akin to that of crystalline minerals.

In his discussion of certain Welsh slates he says :— " Crystalline forces have rearranged whole mountain masses of them, providing a beautiful crystalline cleavage passing alike through all the strata . . . They (the cleavage) planes appear to me only resolvable on the supposition that crystalline or polar force acted on the whole mass simultaneously, in a given direction and with adequate power " [18, p. 477].

In support of this he urged that homogeneity is an essential character in a crystalline mineral mass, and that slaty cleavage is best developed in very fine-grained homogeneous rocks.

In several papers which appeared between 1835 and 1846, electricity and terrestrial magnetism were discussed as possible causes of slaty cleavage. Sedgwick had already observed that over wide areas the cleavage planes were inclined in the direction of the magnetic north*, and R. Were Fox had succeeded in producing lamination in clay by the long continued action of an electric current [19], while Robert Hunt's experiments with electro-magnets also led him to suppose that " the dynamic power of voltaic electricity " may have been responsible for the peculiar structure of slate [24].

* The magnetic north, to which the compass needle points, is not constant: at present, in North Wales, it is between 16 and 17 degrees west of the true or astronomical north, and in 1840 it was 22 degrees west.

Taking all these things into consideration, De la Beche suggested that terrestrial magnetism might, to some extent, have determined the arrangement of the constituents of the rocks they traverse, causing the development, not only of cleavage, but also of other planes of division such as joints [20].

It is not possible in this paper to consider all the investigations which have led to the present-day conception of the origin of slaty cleavage, but further research showed that the significant feature concerning the general direction of the cleavage planes was their association with the trend of the folds into which the rocks have been thrown, rather than their inclination towards the magnetic north, which is not constant, and indicated that the striking development of cleavage in fine grained homogeneous rocks was due to the facility with which the particles of such rocks could accommodate themselves to lateral compression, rather than to the arrangement of the particles according to the laws of crystallisation in minerals.

Daniel Sharpe's observations upon distorted fossils found in certain slates led him to recognise the influence of pressure in the development of cleavage, and he summarises, in the following words, the views he expressed in two papers upon the subject, read in 1846 and 1848 respectively :—" Pressure appears to have been concerned in the operation : for the cleavage is uniformly at right angles to the direction in which pressure is seen to have taken place ; and also the amount of cleavage appears to bear some proportion to the compression suffered by the rock " [25, p. 104]. " In slaty rocks there has been a considerable compression of the mass of rock between the planes of cleavage ; this compression being shown by the distortion of the included organic remains, and the flattening of the component portions of the rock " [26 p. 128]. " Thus all our observations and deductions ultimately converge to the conclusion that the cleavage must be attributed to pressure caused by the elevation of great masses of rock under conditions of which we are ignorant " [26, p. 129].

Darwin's " Geological Observations in South America " (1846), led him to recognise the important part which the formation of new minerals, such as mica, played in the development of cleavage [23, Ch. 6].

H. C. Sorby, who was one of the first to study rocks by means of sections cut sufficiently thin, and therefore transparent enough, to be examined by means of the microscope, applied that method to the investigation of slates, and in a number of papers published between 1853 and 1880 showed that there was evidence of very considerable compression due to lateral pressure [31, 34]. Similar views were also expressed by John Phillips, in a " Report on Cleavage and Foliation in Rocks "

presented to the British Association in 1856 [29], and in the same year by G. Poulett Scrope, in a paper on the formation of volcanic craters. The latter author wrote :—" Of course we are led to connect the movements under extreme pressure to which this peculiar texture of the laminated rocks is here attributed, with the action of the same forces by which these beds have been so generally bent and contorted into a series of folds or wrinkles, more or less at right angles to the general strike."

Scrope's explanation of the nature of the forces concerned, was, however, one that did not find favour, either then or subsequently. He considered the compressing force to have resulted from the uprising of enormous quantities of molten matter from the depths of the earth's crust. This, he argued, would cause the elevation of over-lying strata, and these, when tilted at a considerable angle would, under the influence of gravity, slide laterally away from the centre of elevation, becoming wrinkled and laminated by " the intense pressure compounded of their own weight " [30, p. 348].

It was, by this time, generally recognised that cleavage results from pressure during periods of mountain building movements in the earth's crust, but while some authors laid stress upon the rearrangement and flattening of the original clay particles, others, for example, T. M. Reade and P. Holland [39], were of the opinion that the crystallisation of new minerals such as mica played the more important part.

The probability is that the former process operated mainly in the early stages of the alteration, and the latter towards its close.

From time to time, attempts have been made to reproduce experimentally the properties associated with slate. In 1856, Tyndall, lecturing at the Royal Institution, showed that slaty cleavage could be produced in wax, by subjecting it to great pressure between thick plates of wet glass [32], and between 1870 and 1880 a number of interesting experiments were made by the French geologists, A. Daubrée and E. Jannetaz.

In one of Daubrée's experiments, fragments of a granitic rock were placed with water in an iron cylinder which was rapidly rotated. This resulted in the rock fragments wearing one another away, producing material resembling clay, and may be taken as representing the work done by rivers and the ocean in eroding rocks. The clay was sealed in a wrought iron tube and strongly heated for several weeks, when it was found that minute scales of mica had been formed within the hardened mass.

In the experiment of Jannetaz, a mass of clay was enclosed in a wrought iron container in such a way that intense pressure could be applied to it ; at the end of the experiment the hardened mass displayed distinct traces of slaty cleavage.

The two latter experiments illustrate the effect of heat and pressure in rearranging the particles of a mass of clay, and in developing new minerals among them [12, p. 13].

More recently, G. F. Becker devised an apparatus for compressing wax and clay. His experiments led him to suppose that the usually accepted theories concerning slate formation were inadequate, and that the material obtained relief from the pressure by the development of an infinite number of parallel faults [41].

A list of the more important works in which the nature and origin of slaty cleavage is discussed will be found in the bibliography on page 57.

THE FORMATION OF SLATE IN WALES

Having discussed the general principles underlying the formation of slate, we are now in a position to consider the origin of some of the Welsh slates, and it will be convenient to deal first with those which occur in North Wales.

During the Cambrian period (which, as will be seen from the table of strata on page 54, is one of the earliest of the periods into which geologists have divided the earth's history), most of North Wales was beneath a sea in which a great thickness of mud, sand, and pebbles accumulated. During the long period involved there were many local changes, but the general conditions were such that fine-grained deposits (mud or clay) predominated in Carnarvonshire, while coarser deposits, ranging from fine sand to pebbles, predominated in Merionethshire.

The accumulation of marine deposits continued into the Ordovician period, but although fine-grained muds were laid down in many parts of the area, volcanoes arose locally on the floor of the sea, and vast quantities of lava were poured out upon the sediments that were accumulating, so that in some districts the bulk of the Ordovician formation consists of volcanic rock—either lava, or fragmentary material produced by explosive eruptions, on occasions when the volcanoes actually rose above sea level.

During this period the sea floor must have been slowly sinking in order to permit of the accumulation of so great a thickness of sedimentary and volcanic material, and eventually the fine grained muds were deeply buried beneath the strata which had accumulated upon them.

This covering of newer strata must have been somewhere in the neighbourhood of 25,000 feet in thickness, and in consequence, the underlying material was subjected to enormous pressure, as well as to considerable heat. It is not possible to determine the temperature which was reached, but at the present time, the temperature at a depth of four or five miles beneath the earth's surface is probably well over 400°F.

There was, from time to time, a tendency for the rocks to be laterally compressed and thus made to accommodate themselves to a smaller horizontal space by folding, but at the close of the Silurian period and during the succeeding Devonian period, this part of the earth's crust passed into a state of violent unrest.* The rocks which had already been formed were squeezed, and the pressure appears to have come from the north west as its effect is seen to be more intense in that direction.

As a result of the pressure the sedimentary and the volcanic rocks which had accumulated in the seas covering the site of North Wales during the Cambrian, Ordovician, and Silurian periods, were folded and built up into mountains, which were part of a great chain extending in a direction approximately north-east and south-west. The mountains of Scandinavia and of the North West Highlands of Scotland, are, together with those of Wales, worn-down relics of that ancient range.

The effect of these earth movements upon the strata which they compressed may be illustrated by considering the muds which had accumulated during Cambrian times in the district between Penygroes and Bethesda in Carnarvonshire. Extending from St. Anne's to Llanllyfni there is a long narrow ridge of ancient volcanic rocks : this was in existence before the Cambrian sediments were formed, and in part it contributed to their material. When the pressure from the north-west commenced to operate, the ridge constituted a more or less unyielding mass, which was pushed bodily against the softer clays to the south-east of it, squeezing them against the hard rocks (also largely volcanic) of the synclinal or trough-like folds into which the rocks of the Snowdonian area had been thrown.

* The Caledonian system of earth movements—so called because of the important part which they played in determining the geological structure of Scotland. Mountain building movements neither begin nor end abruptly ; they usually increase in intensity for a considerable time and then gradually die away.

The clays were, in consequence, compelled to occupy less horizontal space, but very little vertical expansion was possible owing to the enormous thickness of strata which rested upon them. The result of this combination of circumstances was that a thick deposit of clay-rock was subjected to considerable heat and to intense pressure in a confined space—conditions which we have already seen are capable of converting clay into slate: we therefore find that in north-west Carnarvonshire the best slates occur where the Cambrian deposits are finest in grain and where they were most influenced by the pressure transmitted by the ridge of ancient volcanic rocks (see Map, Plate 2).

The intense lateral pressure to which these rocks must have been subjected is illustrated in a remarkable manner along the side of Llyn Padarn, where there are beds of conglomerate in which the pebbles themselves have been flattened. The rock is thus described by Ramsay:—"Part of the conglomerate consists of slaty pebbles in a clay matrix, the whole being affected by slaty cleavage, remarkable on account of the pebbles being elongated in the direction of the cleavage lines, and obliquely to the planes of bedding, in accordance with which under ordinary circumstances the flat sides of the pebbles would naturally lie; this arrangement being due to intense pressure, which, in all cases of slaty cleavage, caused the particles composing the rock to arrange themselves approximately at right angles to the direction of the compressing force. In this case these effects are visible, the pebbles having been both lengthened and flattened by the same pressure" [47, p. 179].

Farther to the south east, in the immediate neighbourhood of Snowdon, the clay deposits were thinner, and the cleavage is to a large extent modified by the hard masses of igneous rock with which they are associated, so that there, the slates are not always of commercial value. In the Lleyn Peninsula, also, cleavage was developed in the fine grained sediments, but not sufficiently to yield slates worth quarrying, partly owing to the fact that the south-westerly extension of the hard ridge of volcanic rock which determined the magnificent cleavage of the Bethesda, Llanberis, and Nantlle slates was more deeply buried, and consequently had little or no effect upon the sediments that were being compressed, and partly because the capping of Ordovician volcanic rock was thinner, so that there was greater possibility of the underlying clays obtaining relief from the pressure by movement of the beds as a whole, rather than by the rearrangement and flattening of their constituent particles and the formation of new minerals.

In the neighbourhood of Blaenau Ffestiniog, the shales interstratified with volcanic rocks of early Ordovician age were

also cleaved, giving rise to the grey slates for which the district is so famous.

In other places where suitable clay-like deposits were so situated with regard to the harder beds as to receive the full force of the lateral pressure, slate has been formed : this is the case in the neighbourhood of Corris, and between Dolgelley and Fairbourne.

The effect of the trend or strike of the rocks and their relation to the direction of the pressure, is well illustrated in the poor development of cleavage in the Ordovician rocks between Arenig and Moel Llyfnant in Merionethshire. Here, the rocks are remarkably free from cleavage, although in other respects they are similar to those which, a few miles away, have been converted into good slates ; but, unlike the rocks in the Bethesda-Nantlle slate zone which trend north-east to south-west, at right angles to the direction of pressure, those in the Arenig district lie more or less parallel to the direction of pressure, which the hard igneous rocks withstood to such an extent that the associated shales were very little compressed [64, p. 632].

Similarly, in the neighbourhood of Tremadoc, there is evidence that the rocks have been greatly compressed, but they trend more or less east and west, and of the numerous attempts which have been made to develop them commercially, none has been permanently successful.

In the neighbourhood of Corwen and Llangollen, however, cleavage *has been* developed in rocks which trend in an east to west direction, but this is because in that district the pressure acted from north to south, as indicated by the nature of the folds into which the rocks were thrown. The degree of cleavage depends, as in other cases, upon the nature of the sediments, and upon the relation between their strike and the direction in which the pressure was being applied [73].

Sedgwick appears to have been the first to notice that " where the cleavage is well developed, in a thick mass of slate rock, the strike of the cleavage is nearly coincident with the strike of the beds " [18, p. 473].

The way in which the development of cleavage depends upon the relation between the trend of the rocks and the direction in which pressure is applied may be illustrated if a small rectangular lump of clay is placed between two strips of wood, sandwich fashion, and squeezed in a vice. If the wooden strips lie parallel to the jaws of the vice all the pressure will be transmitted to the clay which will be flattened, but if they are placed transversely to the jaws, the pressure caused

by bringing them together will, up to a certain point, be sustained by the wooden strips, and the clay will scarcely be squeezed at all.

Thick and extensive deposits of pebbles, sand, and clay, such as those which have been concerned in the formation of the slates of North Wales, can only have accumulated as the result of the long continued denudation of an older land area, no trace of which now remains, except in its worn fragments which constitute the present rocks of the district.

The nature of the Cambrian sediments and their distribution suggests (1) that this old land mass lay to the east, because, on the whole, the strata thicken in that direction ; (2) that it was hilly or even mountainous, because some of the streams flowed rapidly enough to transport coarse sandy material, and (3) that its rocks were of a granitic character (using that term in its widest sense) similar to those now seen among the rocks of Anglesey and the ridge of ancient lavas stretching from St. Anne's to Llanllyfni, because the sediments mostly consist of material such as would result from the disintegration of granitic rocks and the decomposition of their minerals.

The clays which are now slates were not necessarily directly derived from the wearing down of granite or granitic rocks, for the material may have been deposited, worn away, and redeposited many times before finally accumulating where it now occurs.

THE DISTRIBUTION OF SLATE

From what has been said of its mode of origin, it will be appreciated that slate can only occur in regions where deeply buried clay-rocks have been subjected to pressure during periods of movement in the earth's crust, and they can only appear at the surface in places where there has been extensive denudation, exposing rocks that once formed part of the deeper layers of the earth's crust.

Since the older the rock the more likely it is to have been deeply buried and to have been affected by earth movements, it follows that slate is more frequently found among the rocks of the earlier geological formations. In this country there are no economically useful slates among strata more recent than those of Delabole and Tintagel in Cornwall, which are of Devonian age, and it is very rarely that they occur in newer strata anywhere.

In the table of strata on page 54 are indicated the principal geological horizons at which slate occurs, not only in Wales, but also in other parts of the world.

The oldest clay-like sediments, namely those of Pre-Cambrian age, have for the most part passed beyond the condition of slate and have become crystalline schists, as is the case in Anglesey, but true slates of Pre-Cambrian age occur in various parts of Scotland, and in Charnwood Forest, Leicestershire. In the latter district the purple and green Swithland slates were at one time extensively worked, but although durable, they were thick and heavy, and since the introduction of railways have been almost entirely superseded by the vastly superior Welsh slates.

Distribution of slate in wales.—As will be seen from the map (Plate 2) on which the distribution of commercially important slates in Wales has been indicated, there are, disregarding certain isolated occurrences, five important slate areas. They are (1) Central Carnarvonshire, where the slates occur in beds of Cambrian age ; (2) The country around Blaenau Ffestiniog where the slates are of Ordovician age ; (3) The country between Towyn and Corris, where both Ordovician and Silurian strata yield slates ; (4) The country between Llangollen and Corwen, where slates occur in the Wenlock and Ludlow divisions of the Silurian formation ; (5) The Prescelly district of Pembrokeshire and the adjacent parts of Carmarthenshire, where the slates are of Ordovician age.

Generally speaking the limits of a slate mass are not sharply defined, but as a series of clays or shales is traced into a disturbed region it is found that cleavage becomes more perfectly developed as the region of most intense pressure is approached, consequently rocks which in a geological sense are slate, but which for various reasons are not of economic importance, occur over considerably wider areas than the map indicates.

The slates of each district have certain special characteristics. Some are highly cleaved and yield thin strong roofing slates, others are less intensely cleaved and are more suitable for conversion into slabs, but for every purpose for which it may be required, Wales produces slate of excellent quality, much of it undoubtedly being the best of its kind in the world.

Slate in the cambrian rocks of wales.—The quarries which extend for about eleven miles in a south-westerly direction from Bethesda, by way of Llanberis and Moel Tryfan, to Nantlle and Penygroes, are in lower Cambrian strata, and they include some of the most famous of all slate undertakings.

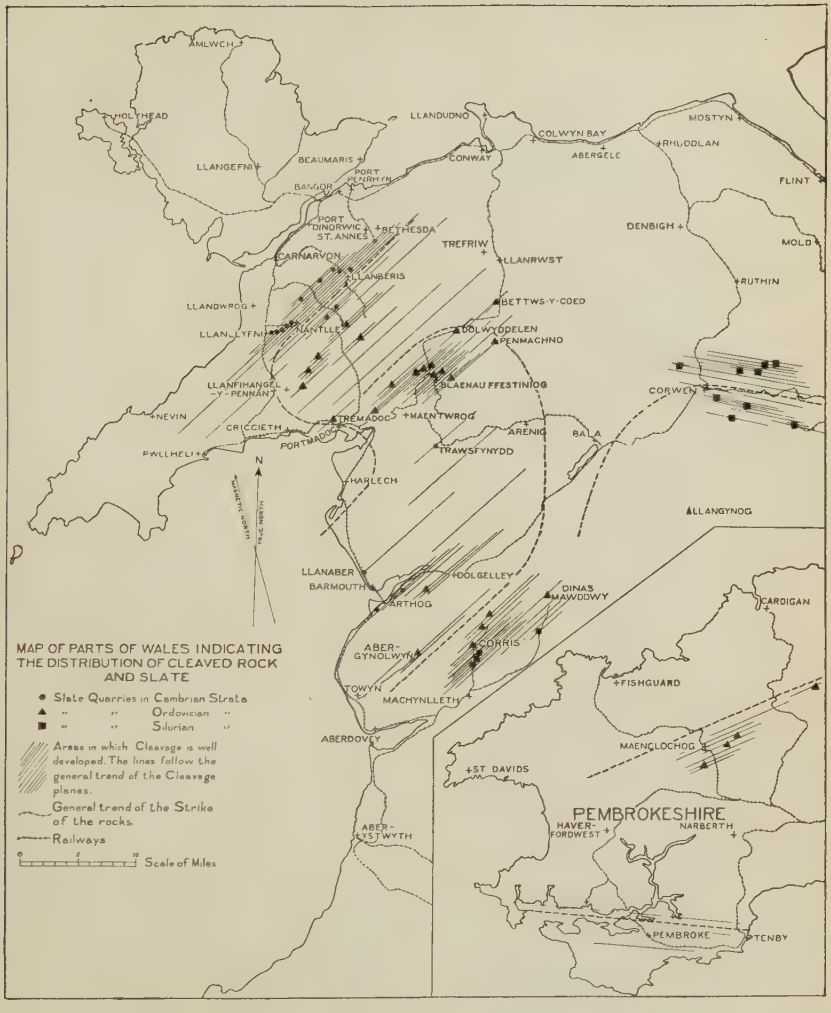
AMLWCH
HOLYHEAD
LLANDUDNO
COLWYN BAY
MOSTYN
RHUDDLAN
ABERGELE
FLINT
LLANGEFNI
BEAUMARIS
CONWAY
PORT DINORWIC
BANGOR
PORT PENRHYN
BETHESDA
ST. ANNES
DENBIGH
MOLD
TREFRIW
CARNARVON
LLANRWST
LLANBERIS
RUTHIN
LLANDWROG
BETTWS-Y-COED
LLANLLYFNI
LLANTLLE
DOLWYDDELEN
PENMACHNO
LLANFIHANGEL-Y-PENNANT
BLAENAU FFESTINIOG
CORWEN
NEVIN
CRICCIETH
TREMADOC
MAENTWROG
PORTMADOC
ARENIG
BALA
PWLLHELI
TRAWSFYNYDD
HARLECH
LLANGYNOG
LLANABER
BARMOUTH
HOOLGELLEY
DINAS MAWDDWY
CARDIGAN
ARTHOG
ABER-GYNOLWYN
CORRIS
FISHGUARD
TOWYN
MACHYNLLETH
ABERDOVEY
MAENCLOCHOG
ST DAVIDS
PEMBROKESHIRE
HAVERFORDWEST
NARBERTH
ABER-YSTWYTH
PEMBROKE
TENBY
N
MAGNETIC NORTH
TRUE NORTH
MAP OF PARTS OF WALES INDICATING THE DISTRIBUTION OF CLEAVED ROCK AND SLATE
Slate Quarries in Cambrian Strata
" " Ordovician "
" " Silurian "
Areas in which Cleavage is well developed. The lines follow the general trend of the Cleavage planes.
General trend of the Strike of the rocks.
Railways
Scale of Miles

PLATE 2.

There are several beds or " veins " of workable slate with indifferent slates or sandy beds between them ; the thickness of the whole series varying from 500 feet in some places to 1,000 feet in others.

Most of the slates are reddish-purple or blue in colour but some of the upper " veins " are green. The two largest quarries are the Penrhyn quarry and the Dinorwic quarry which are situated on opposite sides of the Elidyr Mountain—the former being on the north-east, overlooking the valley of the Ogwen, and the latter on the south-west, overlooking Llyn Peris.

Fossils are almost entirely absent from these rocks except for a few examples of the trilobite, *Conocoryphe viola*, found in the green slates at the top of the Penrhyn quarry.

The discovery that the slate contained fossils was made in 1887 by Edward Jones and Robert Lloyd, two Penrhyn quarrymen, and was of considerable importance as it furnished evidence concerning the geological age of the slates, and indicated that the Penrhyn quarry slates arose from the cleavage of material which accumulated during the earlier part of the Cambrian Period : that is to say the rocks are of Lower Cambrian age and belong to the Georgian or *Olenellus* series of geologists [57].

Subsequently other examples of *Conocoryphe* were found in the same part of the quarry by the late Professor T. McKenny Hughes, and Robert Lloyd discovered trilobites, too obscure for accurate determination, in strata 1,200 feet lower down [58].

The slates trend in a south-westerly direction, and at Llanberis they are worked in the Dinorwic quarries on the north-eastern side of Llyn Peris. There have also been extensive workings (Glynrhonwy quarries) on the opposite side of the valley, above Llyn Padarn.

In the Nantlle valley about 6 miles south-west of Llanberis the slate outcrops occupy lower ground, and the quarries take the form of deep chasm-like pits. This is a handicap to the growth of the industry because the expense of keeping the pits free from water, and of hoisting useful slate and rubbish to the surface, is considerable. The slates in this district tend to have a purple or reddish tinge, and some of the quarries (Dorothea, Penyrorsedd) rank among the largest in the country.

Each of the three principal groups of quarries in this district has its own port of shipment on the Menai Straits. The Bethesda slates are shipped from Port Penrhyn, Bangor ; those of Llanberis from Port Dinorwic, about three miles to the south-west of Bangor, and the Nantlle slates from Carnarvon. The slates from Bethesda are known as " Penrhyn "

slates from the quarry's association with the Penrhyn family, and those from Llanberis are also called " Dinorwic " or " Velinheli " slates. Dinorwic is the present name, and Velinheli the old name of the port from which they are shipped : the name Velinheli (Y Felin Heli) refers to an old salt-water mill, the wheel of which was turned by the ebbing of the tide in the Menai Straits.

Slates occur in the uppermost part of the Cambrian formation (Tremadoc Beds and Dolgelley Beds), around the northern and eastern margin of the Harlech dome* and have been quarried in various places, such as at Nant-y-Derbiniad, north west of Arenig [64, p. 613], at Carreg-y-David on Rhobell Fawr between Arenig and Dolgelley [50, p. 795], near Arthog, and near Fairbourne. The slates in the Dolgelley Beds are very black, owing to the presence of pyrites in a form which readily decomposes causing the slate to become rusty in appearance. On this account, although the slates are easily worked, none of the small quarries which have been opened has proved successful.

Red slates were formerly quarried, to a small extent, south of Trawsfynydd [47, p. 143], and there are also slates in the Cambrian rocks of other parts of the Harlech dome, such as near Llanbedr where there are purple and green slates like those of Llanberis, but owing to the frequent occurrence of hard sandy bands, they are not suitable for exploitation on a large scale, especially as for the most part they occur in low-lying ground and would have to be worked by means of shafts leading to underground mines [97, p. 36].

Slate in the ordovician rocks of wales.—Slates occur among the Ordovician rocks of the Snowdonian region. The rocks have approximately the same trend as the Cambrian strata to the north-west of them, and there are several parallel tracts of country in which slates have been worked.

The most important of these extends from near Bettws-y-Coed in the north-east, to Llanfrothen in the south-west, a distance of about twelve miles. The most valuable slates occur near the centre of the region, that is, around Blaenau Ffestiniog.

Here, the slates are, on the whole, finer in grain than those in the Bethesda-Nantlle district, and they are mostly blue or grey in colour and often have lustrous surfaces.

There are at least seven bands or " veins " of workable slate separated by bands of hard sandy rock, called " hards " by the quarrymen. The veins vary from 10 to 50 yards in

* The Harlech dome is the mountainous district extending from Portmadoc to Arenig, and from Ffestiniog to the Barmouth estuary. It consists of Cambrian deposits, mostly of a sandy or gritty nature, and is so called because its geological structure is essentially that of a dome-shaped fold, of which Harlech is nearly the centre.

thickness, but some are, in places, considerably thicker. On account of the fine grained material out of which they were formed, the cleavage of some of the slates in this district is remarkably perfect, making it possible to obtain very thin sheets.

Most of the slates are obtained from underground mines, of which the following are the best known of those now working :—Croesor, Diphwys, Llechwedd, Maen Offeren, Manod, Oakeley, Votty and Bowydd. The slate is sent to Portmadoc for shipment.

In the northern part of this slate tract are the once famous quarries at Penmachno and at Dolwyddelen (Prince Llewellyn), where the slates are very black. Dark blue slates are obtained near Bettws-y-Coed, and at Rhos, between that place and Capel Curig.

Other workable slates of Ordovician age occur in the tract of country extending from between Criccieth and Tremadoc in the south-west, to the Conway River near Trefriw, in the north-east. There are several more or less parallel lines of quarries and mines, some of which are still worked : one such line of quarries, mostly disused, extends from Llanrhychwyn* (near Llanrwst) to Llyn Dinas and Beddgelert ; another extends from Bwlch-cwm-y-llan (between Snowdon summit and Yr Aran) to a point north of Tremadoc, and another from Rhyd-ddu (Glan-yr-afon and Llyn-y-Gader quarries) by way of the Dwyfawr valley towards Llanfihangel-y-Pennant. The slates have been worked on both sides of the Dwyfawr Valley, but the most important quarries were situated on the eastern side. They include the once famous Hendre-ddu quarry near Llanfihangel, and the Cwmtrwscwl quarry (Cwm Trwsgl) in a small tributary valley between Y Garn and Moel Lefain.

Another group of quarries in slate of Ordovician age occurs in the neighbourhood of Abergynolwyn, Corris, and Aberllefenni, in south Merionethshire and the adjacent part of Montgomeryshire. Here, extending from Towyn in the south-west to Dinas Mawddwy in the north-east, is a series of mudstones some 1,500 feet in thickness, belonging to the Bala division of the Ordovician series. The cleavage is best developed in those beds which are fine grained and homogeneous, and is nearly parallel to the general southwesterly-northeasterly trend of the rocks. There are two important slate " veins " in this district (the " Broad Vein " and the " Narrow Vein "), and quarries have been opened in them wherever the cleavage is sufficiently well developed [67]. The relation between the Corris-Aberllefenni slate zone and the more or less rigid mass

* Llanrhwchwyn of the old ordnance maps.

formed by the hard gritty beds of the Harlech dome and the volcanic ridge of Cader Idris, is similar to that which exists between the Bethesda-Nantlle slate zone and the St. Anne's-Llanllyfni volcanic ridge, which, it has already been shown, was so situated with regard to the direction in which the pressure was being applied, as to move bodily against the softer sediments on its south-eastern side, squeezing the soft clays and converting them into well cleaved slates. The slates from the Abergynolwyn district are sent by the Tal-y-llyn Railway to Towyn, and those from Corris and Aberllefenni by the Corris Railway to Machynlleth.

Slates of similar age also occur at Llangynog in Montgomeryshire where they have been worked for many centuries, and at Cader Berwyn, about three miles south-east of Llandrillo in Merionethshire : here, however, the mines have long since fallen into disuse.

The Ordovician rocks between Dolgelley and Fairbourne also exhibit cleavage, all the softer beds having been affected ; fossils were fairly abundant in the original shales, and they have not been entirely destroyed, particularly where the direction of cleavage and that of original bedding coincide, as they do, in places where the strata are highly inclined [66].

Cleaved shales of Ordovician age have been quarried at Penrhyn Gwyn on the slopes of Cader Idris, and they also occur near the Llynau Crogenen, Arthog, but there the rock has not been worked for roofing slate.

Although the rocks of Anglesey exhibit to perfection the results of compression due to earth movements, the older (Pre-Cambrian) rocks of the district have passed beyond the condition when slaty cleavage was their most conspicuous feature, and they are for the most part completely crystalline schists. Some of the shales in the Ordovician series, however, exhibit good cleavage, and in times past roofing slates have been quarried at Llaneilian, near Amlwch. They are not as good as the slates of Carnarvonshire but might well be used for local farm outbuildings [51, p. 853].

A third important group of quarries in slate of Ordovician age occurs in the neighbourhood of the Prescelly Mountains, Pembrokeshire, and the adjacent parts of Carmarthenshire, and Cardiganshire.

The slates occur in the middle part (Llandeilo Series) of the Ordovician formation. Those near Clydey (Glogue quarries) are bluish grey, but those of the Prescelly district (Maenclochog, Llandilo. and Gilfach) range from olive green to silvery grey, and are probably made up to a large extent of volcanic dust, rather than of the more usual type of marine clay.

Cleavage has been developed in other Ordovician strata and in some of the Cambrian strata near Abereiddy in northern Pembrokeshire, but the rocks either weather very readily, or have so many hard grit-bands associated with them as to be of no commercial value, and although numerous quarries have been opened, none has proved successful [77].

Slate in the silurian rocks of wales.—Slate quarries and mines have been opened in rocks belonging to the lower division of the Silurian system (Llandovery or Valentian Series) near Esgairgeiliog between Corris and Machynlleth, and in the upper part of the Silurian system (Wenlock Series and Ludlow Series) between Llangollen and Corwen, in the south-eastern corner of Denbighshire and the adjacent part of Merionethshire. In the latter area the slates are dark grey-blue in colour, and the cleavage is less highly inclined to the horizon than is the case with the older slates of Carnarvonshire : in the Wenlock beds slates are worked in quarries and mines at Moel Fferna, Glyn Ceiriog, Moel-y-Faen, and Pen-y-glog near Corwen, and in the Ludlow beds at Glyndyfrdwy and Rhewl. Roofing slates were formerly quarried at Pentre-dwfr, north of Llangollen, but although they weather well they are too thick for modern requirements. Between Glyndyfrdwy and the immense disused quarry at Clogau about four miles north of Llangollen, the Ludlow beds consist of " rapidly alternating beds of cleaved mudstone and uncleaved laminated silt . . . the rock splits readily between the cleaved and uncleaved layers into huge slabs of a uniform thickness and has formerly been extensively quarried for slabs, cisterns, flags, etc." [73, p. 205]. These slab-yielding rocks which are similar in age to the " Nantglyn Flags " of the Vale of Clwyd [68] are, strictly speaking, " flags " rather than " slates," because although they exhibit cleavage, they split most readily in the direction of bedding.

Fossils are more frequently found at certain horizons among these slates than is the case in the older slates, partly because the Silurian rocks are on the whole richer in fossils, and partly because the beds have been less intensely cleaved.

The slates from the Cambrian Quarry near Glyn Ceiriog often split so as to expose large surfaces completely covered with various kinds of graptolites ; and the long straight shells of *Orthoceras*, of which there is an excellent example* in the geological gallery of the Museum, are of frequent occurrence in other beds. The *Orthoceras* shells were sufficiently hard and strong to interfere with the cleavage of the rocks immediately adjacent to them.

* Presented by Mr. F. E. Rooper.

At Bettws Gwerfil Goch, about four miles north-west of Corwen, a pale coloured slate, also of Silurian age, has been worked, but not extensively, owing to its remote situation.

Slate in the Old Red Sandstone and later strata of Wales.—The Old Red Sandstone and the Carboniferous Rocks of south Pembrokeshire and the adjacent part of Carmarthenshire were affected by pressure during a series of earth-movements which commenced towards the close of the Carboniferous Period.*

In this area some of the finer grained sediments (marls) of the Old Red Sandstone and the shales of the Coal Measures have been cleaved, but rarely to such an extent as to render the rock suitable for roofing slates. Certain beds in the Old Red Sandstone Series of the Island of Skokholm, which lies to the west of Milford Haven, yield slates of peculiar colours (pink and green), and they were once worked for roofing local farm buildings [78, p. 166].

The cleavage in the older (Cambrian and Ordovician) rocks of north Pembrokeshire was, like that in North Wales, produced during an earlier (Caledonian) period of rock folding.

CLEAVAGE AND THE BEDDING OF ROCKS

Slaty cleavage in different kinds of rock.—Not all kinds of rock are equally susceptible to cleavage. A rock consisting of very fine particles, all more or less similar in character and size, is more liable to be cleaved than one consisting of coarse or mixed material.

Sandy beds alternating with clay deposits do not yield good slates, and, instead of splitting readily into sheets of any thickness, they split imperfectly and at irregular intervals, as illustrated in Fig. 2, where a thin gritty band in slate has been much less regularly cleaved than the remainder of the rock.

This is partly due to the fact that the particles in a coarse grained or sandy rock are larger and better able to resist the rotational influence of pressure than those of a fine grained soft rock, so that when they have been squeezed as closely together as is possible, they tend to interlock with one another much more than is the case with the component particles of

* The thrusting force came, in the main, from the south, and it involved the South of England, Wales and Ireland, as well as Brittany: it is known as the Armorican system of earth movements, Armorica being the ancient name of Brittany.

clay, and partly because coarse grained sedimentary rocks do not usually contain an abundance of mineral particles capable of being converted into mica when subjected to heat and pressure.

If the experiment of compressing a bag of counters were to be performed with a bag containing marbles or walnuts, it would not be possible to pass a knife through the mass as easily as in the previous case, even although the pressure may have caused all the nuts to arrange themselves in similar positions.

Not only is the cleavage less perfectly developed in a rock like sandstone, but where sandy and clayey beds alternate, the direction of the cleavage is different in the two kinds of rock. It makes a lower angle with the bedding in the case of the clay than in the case of the hard rock. Figure 3 shows, diagrammatically, the varying relation between cleavage and the bedding planes where hard and soft strata alternate.

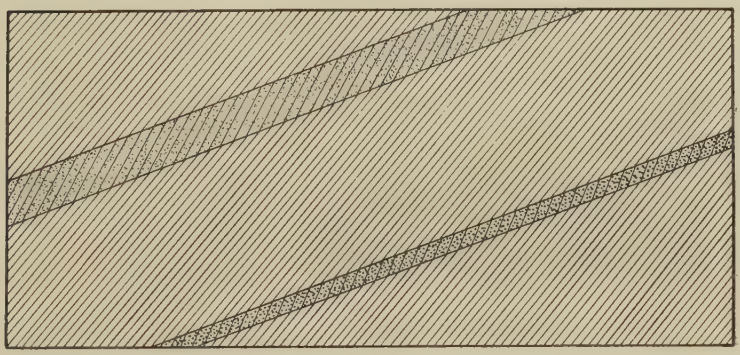

FIGURE 3.—Beds of sandstone associated with slate. cleavage planes are usually bent on passing from a fine-grained into a coarse-grained rock.

Rotation and the formation of new minerals are the essential features in the development of cleavage, but there are also indications that the material was shifted, either by a general flowing of the particles, or in slices which moved along planes of fracture called "faults." It is often found that when a mass of slate is traversed by a band differing in colour from the rest, the band shows evidence of faulting, as in the case of the specimens illustrated in Fig. 4*.

In such specimens, the fact that the rock has been divided into sheets that have moved relatively to one another is quite

* The specimen represented by 4a was presented by Mr. G. J. Williams, I.S.O., and that by 4b by Mr. A. B. Badger.

apparent in the neighbourhood of the coloured band, but the remainder of the slate shows little, and in most cases, no evidence at all, of the existence of the faults. Obviously, then, any slate mass may be, and most no doubt are, traversed by faults, but they are not apparent if the rock is of uniform colour, and they do not necessarily represent present planes of weakness because the whole mass was welded together as the pressure continued to be applied.*

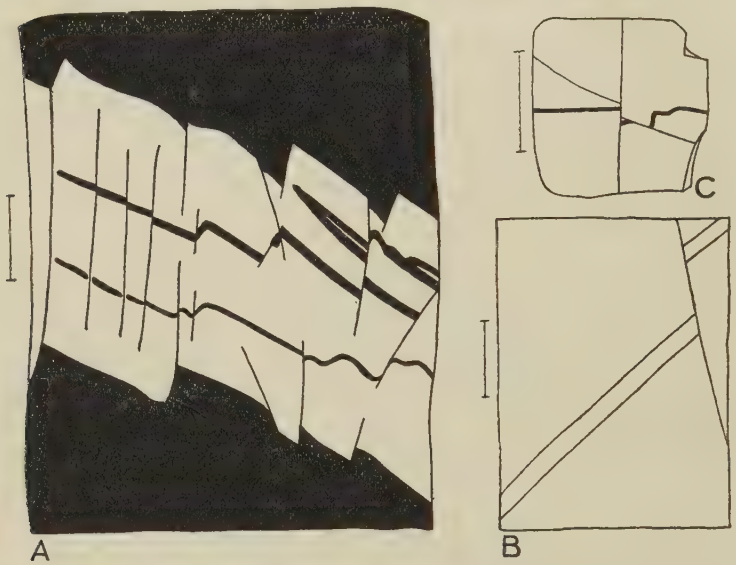

FIGURE 4.—Small faults in slate.

A, a series of faults rendered evident by their effect upon a green gritty band in a purple slate from Nantlle, Carnarvonshire.

B, a fault displacing a green band in a purple slate from Carnarvonshire.

C, a slate from the Lake District in which a thin dark band has been affected by two faults.

The vertical lines to the left of the diagrams each represent 3 inches.

The foregoing remarks relate to small faults within the mass of the slate; regarded as a constituent of the earth's crust, slate beds as a whole are liable to be shifted by faults just like any other rock.

Evidence of original bedding in slates.—Slates were originally "bedded" or "stratified" rocks, and as such, must have been deposited as layers more or less horizontally arranged, but the development of cleavage has often entirely obliterated the original stratification.

* Faults are fractures which traverse the rocks of the earth's crust, and along which there has usually been differential movement of the rocks on either side of the fissure.

Usually, before the stress became intense enough to produce cleavage, the rocks sought relief from the lateral pressure by passing into a folded condition, so that, taking a fairly large area into consideration, the direction of cleavage may coincide with the direction of bedding, or may intersect it at almost any angle, as may sometimes be seen when large surfaces of slate are exposed in extensive quarries (Fig. 5).

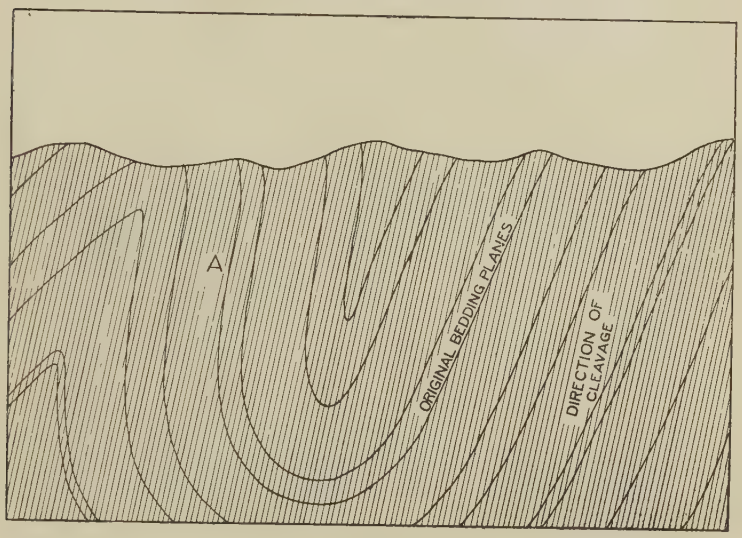

FIGURE 5.—Cleavage and rock-folding.

Diagrammatic sections across part of the earth's crust in a slate region, where the rocks have been thrown into folds and cleaved as a result of pressure which has acted more or less horizontally to the surface of the earth.

At A, the direction of original bedding and cleavage coincide, and in other places they intersect at varying angles.

The stratification of the original deposits is sometimes indicated by the occurrence of regular layers of well-cleaved slate between beds of indifferently cleaved material (corresponding to beds of fine clay or shale alternating with harder rocks such as sandstone) and occasionally by the preservation of traces of the thin layers or laminae of which each bed consisted. This may be illustrated by reference to the Coal Measures. There may be, between any two coal seams, a considerable thickness—say 30 yards—of shale, which will consist of a very large number of thin layers, each no thicker than cardboard.

The small-scale bedding or lamination may be indicated in the slate mass by bands of colour, each representing a layer slightly different in composition from its neighbours. Even

if there is no difference in colour there may be a stripy appearance owing to variations in the texture of the original deposits. This is beautifully illustrated in some of the slates at Glyn Ceiriog, near Llangollen.

Unless it is of such a nature that it gives rise to planes of weakness in the rock, the existence of traces of original lamination does not affect the commercial value of the slate, except in so far as the presence of coloured bands may spoil its appearance; but the large scale bedding is of importance, because, in general, the composition of a bed of rock capable of conversion into slate is usually uniform for considerable distances, so that if a certain bed produces good slate, the development of the quarry or mine will involve the following of that bed, or as it is usually termed by quarrymen, the "vein",* and in order to do this it may be necessary to remove, as well, considerable quantities of material belonging to adjacent beds. This is one of the reasons for the great amount of waste material that is produced in the course of slate quarrying, and for the development of mines when the amount of useless superincumbent material is too great to be removed. This matter will be referred to again when slate quarrying is discussed.

Fossils in slate.—Fossils are rarely found in slates. The sediments from which the oldest slates were formed are not as a rule fossiliferous, and in the slate formed from later (Ordovician and Silurian) deposits which accumulated during a period when marine life was abundant, fossils that may have existed in the original shales have usually been obliterated during the readjustment of the particles: occasionally, however, especially when the direction of bedding and that of cleavage coincide, fossils may be seen, flattened and distorted in various ways [28, 25]. This is well illustrated by exhibited examples of the trilobite *Angelina sedgwicki* from the Tremadoc Beds near Portmadoc (see Fig. 6), and other fossils.

Well-cleaved slates such as those used for roofing slates will not break along the bedding planes even if those planes can be detected in one or the other of the ways indicated, but others, less well cleaved, may occasionally be broken in the direction of the original bedding. This fact is made use of by those who attempt to collect fossils in slaty rocks. Unless the directions of cleavage and of bedding coincide, it is useless to

* In its relation to the surrounding rocks a slate "vein" is similar to a coal seam (also occasionally called a "vein") except in being very much thicker and, usually, much more steeply inclined. In metalliferous mining, "vein" has quite a different meaning. Veins, or lodes, containing ores are usually relatively thin, wall-like masses, irregular in thickness and in contents. They bear no definite relation to the stratification of the rocks in which they occur, but cut through them and frequently occupy fissures due to faults or joints.

look for fossils on the cleaved surface—that is, on the surface produced by dividing the rock in the direction in which it will split most easily, but if the rock can also be broken to expose the bedding planes, fossils—usually much compressed or distorted—may be seen upon them. As this is a matter requiring much skill and patience, fossils are seldom detected in slate, even when they are present.

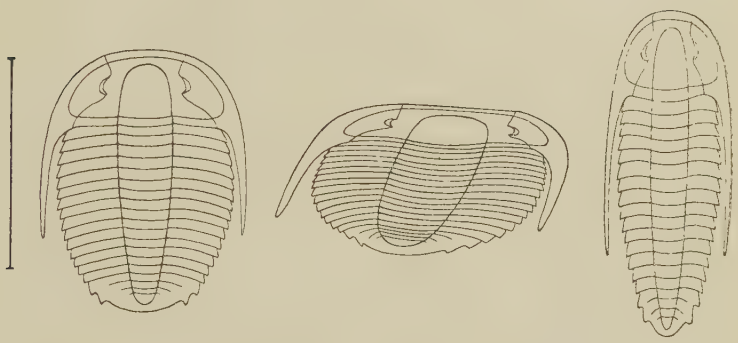

FIGURE 6.—Distortion of fossils in slate.

Examples of the trilobite *Angelina sedgwicki* Salter, from the Tremadoc Beds, near Portmadoc, illustrating the manner in which fossils may be distorted as a result of pressure during the formation of slate.

A typical specimen of the trilobite is depicted in the left hand outline; that in the centre has been compressed obliquely from head to tail; and that on the right, symmetrically from side to side. The vertical line represents 2 inches.

The oldest slates which in this country have yielded fossils, are those at Bethesda in which trilobites have been found (see page 25).

In some of the clays from which the slates of the Berwyn Hills and the mountains north of Llangollen were formed, there are thin bands of limestone composed largely of fossils, among which, fragments of the stems of crinoids or "sea lilies" predominate, and these limestone bands were strong enough to resist cleavage almost entirely, with the result that the rock may be broken easily in the direction of bedding wherever the fossil layers occur, while in the intervals between them it cleaves exactly like any other slate mass. The frequent occurrence of graptolites in the Wenlock beds, and of shells in the Ludlow beds of this district has already been mentioned.

THE COMPOSITION OF SLATE

The colour of slate.—Slates vary considerably in colour. They may be quite black or pale grey, and between those extremes are varying shades of blue, purple, red, and green,

but although the colour of a slate may affect its sale on purely aesthetic grounds, it is not necessarily a criterion of quality, which depends upon properties that are not indicated by the colour of the rock.

The colour of a slate may be due to its original chemical composition, or to the changes which it has subsequently undergone.

It was formerly supposed that all black and dark grey slates owe their colour to the presence of carbonaceous matter, resulting, no doubt from the decomposition of organic matter on the sea floor ; but it is more than likely that in many cases the dark colour is due to the presence of pyrites (iron sulphide) in a very fine state of subdivision. Carbon is certainly present in some slates, but chemical analysis reveals that it is of less frequent occurrence than sulphides of iron.

It has been shown that the very black slates among the Cambrian strata between Dolgelley and Arenig owe their colour to finely divided sulphide of iron, as also do certain modern black marine muds [15]. In the case of the latter it is believed that the iron sulphide results from the combination of iron compounds present in the sea water, with sulphuretted hydrogen liberated by certain kinds of bacteria.

In some slates, the pyrites, instead of remaining as very finely divided particles scattered throughout the mass of the rock, has been crystallised and occurs as shining brassy crystals, usually cubes or some related crystal form, and, for pyrites, such crystals are often remarkably durable. The presence of crystals of pyrites is obviously objectionable in the case of slate required for electrical purposes or (because they are harder than the rock) in slate that is to be polished.

It has been shown, in the case of the slates of Penrhyn and those of Blaenau Ffestiniog, that the pyrites crystals were formed at an early stage in the alteration of the rocks and that they influenced the arrangement of the material in their immediate neighbourhood. The crystals are often accompanied by little elliptical masses of crystalline quartz [4].

Haematite (anhydrous* peroxide of iron) is responsible for the tint of purple and red slates—the slates becoming redder as the quantity of haematite increases. A green mineral, chlorite, resulting, like the mica, from mineralogical changes during the conversion into slate, is often associated with haematite in purple slates. Chlorite is largely responsible for the colour of green slates, which, in general, have less iron and more magnesia than the purple and red varieties. The

* Anhydrous—without water : the powder of haematite is blood red, while that of the hydrated oxides of iron, that is, oxides of iron with combined water (for example, limonite), is rusty brown.

paler shades of olive green and grey are often found in slates that have been heated as the result of the intrusion of igneous rocks among them. Originally, such slates may have been darker in colour owing to the presence of carbonaceous matter, since dissipated by the heat to which the rock has been subjected.

If the original composition of the rock and the extent of the alteration which it has sustained, have given rise to the formation of more mica than is usually the case, the surface of the slate will have a shimmering appearance. Very lustrous and highly micaceous slate is called Phyllite, and occurs, for example, in various parts of Anglesey, and in Cornwall.

Chemical changes within the slate, or along cleavage planes which have become slightly open as a result of weathering, may result in the rock fading or taking on a stained and mottled appearance. Slates of this type, known as " Rustic slates," are often used for special purposes where an ornamental effect is desired. Some of the quarries in the Prescelly district of Pembrokeshire are famous for slates of this kind. The percolation of water along cleavage planes has given rise to deposits of oxide of iron, causing the slate to exhibit various tints of red and brown in addition to its characteristic greenish-grey colour. Properly used, such slates are capable of producing a picturesque effect, as in the case of the Library of the University College of South Wales and Monmouthshire, Cardiff. Other examples of rustic slates (dark blue with red stains, due to iron) are to be seen in North Wales, for example, on the roof of the church at Maentwrog. Stained slates are present to some extent in most slate quarries, although, as a rule, they are too irregular in their occurrence to be made an article of regular trade.

Spots in slate.—The colour of " rustic slate " is usually entirely on the surface, but some slates have spots and blotches in their mass. Purple slates frequently have green patches which detract from their appearance although they do not affect their wearing properties.

The difference in colour probably existed before the cleavage was developed, for the spots are usually oval, as though they were originally spherical but had been compressed, and they are seen to be affected by the small faults which are so prevalent in slates. The green spots probably represent places where decaying organic matter caused a reduction of the iron present in the original mud as it accumulated on the sea floor.

The spots frequently pass into continuous bands which follow the bedding of the rock and they are often associated

with coarse sandy material ; the green bands, also, appear to be due to the reducing effect upon iron of decomposing organic matter, and it has been suggested that the conditions which gave rise to the accumulation of sand were also favourable to marine life [12, p. 26].

THE COMPOSITION OF SLATE.—From what has been said concerning the colour seen in different kinds of slate, it will be realised that they differ slightly in chemical composition, but the differences are almost entirely in the non-essential constituents.

Silica* and alumina constitute about 80 per cent. of all slates, and the average of a large number of analyses reveals that as far as silica, alumina and iron oxide (the most abundant constituents) are concerned, slates are practically identical in composition with shale. This is what would be expected ; for although the arrangement of the material into minerals may have changed during the development of cleavage, nothing has been added and nothing removed. Other materials present include magnesia, potash, lime, soda, and water.

Of greater interest than its chemical composition is the mineralogical composition of slate, and this can be determined by the examination of very thin slices under the microscope.

The minerals most commonly found in slate are the variety of mica known as muscovite,† chlorite, and quartz. Some of the mica and most of the quartz may represent particles originally present in the clay, but most of the mica and the chlorite were formed as the constituents of the original particles entered into new chemical combinations in the manner already indicated.

Other minerals, which may or may not be present, include pyrites, haematite, magnetite, graphite, biotite (a dark iron-bearing mica), rutile, tourmaline, and zircon. The four last mentioned, at least, are probably unaltered fragments of the original granitic rocks from which the clay was formed ; the graphite results from the crystallisation of carbonaceous matter, and the haematite from the crystallisation of oxides of iron in the clay.

* Although its name may be unfamiliar to those who have not studied geology, silica is the commonest constituent of the earth's crust, of which, either alone or in combination with other oxides, it forms about 60 per cent.
Silica is a compound of oxygen and silicon, but although the latter is the second most abundant element it never occurs naturally in the free state, and when artificially isolated from its compounds is little more than a scientific curiosity.
Silica is the principal component of such well known materials as sand, sandstone, flint, quartz, agate, chalcedony, and many other rocks and minerals.
Alumina is a compound of aluminium and oxygen.

† Muscovite (potash-mica, or white mica) contains potash and alumina combined with silica : chlorite contains magnesia, iron and alumina combined with silica.

THE TEXTURE OF SLATE.—The texture of slate depends to a large extent upon the size of the grains of which the original rock was composed.

Rocks of fine and uniform grain yield smooth varieties of slate, and those which contain relatively large particles of hard minerals like quartz, that remain practically unaltered during the development of cleavage, give rise to coarse rough-feeling slates.

PREPARATION OF SLATES FOR THE MARKET

QUARRIES AND MINES.—Slate is sometimes obtained from open quarries, and sometimes from underground workings, or mines.

If the strata in which slate occurs are steeply inclined, the appearance of a certain slate bed at the surface implies that the same slate will be found to extend downwards for a considerable distance, and it can either be followed downwards by means of deep open chasms as in the Nantlle district of Carnarvonshire, or it may be worked by means of terraces cut into the face of a mountain as in the case of the quarries at Llanberis and Bethesda (see Fig. 7).

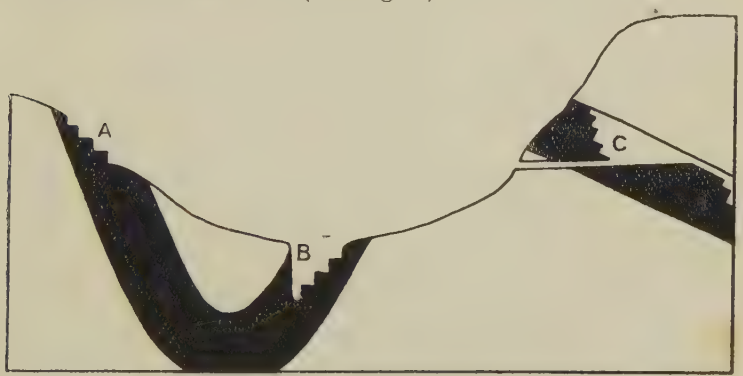

FIGURE 7.—DIAGRAMMATIC REPRESENTATION OF A SLATE BED, WHICH, OWING TO FOLDING, 'OUTCROPS' ON BOTH SIDES AND AT THE BOTTOM OF A VALLEY.

The diagram illustrates the general conditions which determine the development of open quarries on the mountain side (A), deep open pit-like quarries (B), and, when the inclination of the slate bed causes it to pass beneath a considerable thickness of waste rock, of underground workings (C).

If, on the other hand, the strata are inclined at low angles, say 45°, a given band of slate rapidly passes beneath other

strata, and the maintenance of open quarries would soon involve the removal of an overburden of useless material thicker than the slate bed itself. In such cases, mining is resorted to : this is done in the Blaenau Ffestiniog district and in other parts of Merionethshire. Inclined shafts are made into the mountain, and from them, levels are driven into the various slate veins, and the slate is removed, giving rise to large chambers separated by pillars which are left to support the "roof." Work is carried on simultaneously at different levels and at several points on each level, so that a slate mine consists of a series of cavities in a mountain, all of which are being steadily increased in size until as much slate as can be removed without causing a general collapse, has been won.

The magnitude of such mines may be gathered from the fact that the chambers may be as much as 120 feet long, 40 feet wide, and 100 feet high ; in one company's mine in the Ffestiniog district there are fifteen levels, the lowest of them being over 1,500 feet from the top of the inclined tramway which gives access to them. In a horizontal direction the workings may extend for a mile, and work may be carried on simultaneously in as many as fifty chambers [102].

Welsh slate quarries, also, are of unusual size. The Penrhyn and the Dinorwic quarries are claimed to be the largest in the world. These quarries are situated, the former, on the north-eastern side and the latter on the south-western side of the Elidyr mountain. Both consist of a series of step-like ledges or terraces, each about 70 feet from the one below it, the topmost terrace being about 1,800 feet up on the shoulder of the mountain. Work proceeds simultaneously on each of the terraces.

In removing slate from mines and quarries, advantage is taken of any tendency on the part of the rock to break in particular directions.

Cleavage, as a direction along which slate masses may be divided, has already been referred to, but there are also other planes of weakness in slate. It is found that a block of slate may be divided more easily in a vertical direction at right angles to the cleavage than in a horizontal direction. This arises from a structural feature known as "grain," which may, in part, be due to the fact that some of the mica crystals are, as already indicated, arranged parallel to the direction of pressure, and not across it. Roofing slates, which are usually rectangular, have, on this account, to be made so that their greatest length is in the direction of the grain and not across it ; if the reverse were done they would tend to break easily when in use. As a rule, this tendency to break along the direction

PLATE 3.—Part of the Dinorwic Quarry, Llanberis.

PLATE 4.– Removing blocks of slate from the quarry face, Penrhyn

of grain is an aid in the quarrying of slate, but occasionally, as in parts of the south Merionethshire slate area, it is so strongly developed as to make the production of blocks of suitable size a matter of considerable difficulty [67, p. 523].

Daniel Sharpe, whose researches in connection with slate have already been mentioned, attributed the grain* of slate to the fact that as the constituent particles were being arranged with their flat surfaces parallel to the cleavage, as has already been described, they took up positions with their long edges parallel to the inclination of the cleavage, and a slate would naturally tend to break more readily across the cleavage in a direction parallel to the longer edges of its particles, because the shorter edges would interlock to a greater extent. If, in this connection, Fig. 1c be considered as representing diagramatically the surface of a cleaved sheet of slate, such a sheet would obviously break more easily in a vertical direction than in a horizontal direction.

Slate, like most other rocks, is affected by joints or regularly arranged cracks, which have developed subsequently to its formation. They are, to a large extent, the result of shrinkage during the consolidation of soft incoherent sediments into compact rocks, and may be compared to the cracks which appear in starch and clay as they dry, but stresses resulting from movements in the earth's crust have probably played some part in their formation. There are usually two or more sets of joints which intersect at angles approaching a right angle : they may appear as actual cracks in the rock or they may be present as invisible planes of weakness, but in any case they divide the rock into more or less rectangular blocks and facilitate the removal of stone from the quarry face. If, however, the joints occur very close together they may render the slate useless commercially, causing it to break into pieces too small for conversion into roofing slates or into slabs.

Jointing differs from cleavage in that a rock can only be divided where joints actually occur, while in the direction of cleavage it may be split at any point.

Taking advantage of jointing, cleavage, and " pillaring," as the tendency to break vertically at right angles to the cleavage is called, large, more or less rectangular blocks are removed from the quarry face, sometimes with the assistance of explosives (see Pl. 4). The large blocks are divided into smaller blocks weighing from one and a half to two tons ; these are sent to the machine sheds where they are split along cleavage planes into sheets about three inches thick, and then

* Used in this sense, the word " grain " has no relation to the size of the particles, as in terms like fine-grained or coarse-grained, but is similar to its application in the " grain " of wood.

sawn into blocks approximating to the length of the required roofing slate. The sawn blocks are split by hand. A chisel is placed in a certain position against the edge of the block and lightly tapped with a mallet; a crack appears in the direction of cleavage, and slight pressure with the chisel serves to split the block into two pieces with smooth and even surfaces (see Pl. 6). This is repeated until the original block is converted into sixteen or eighteen separate slabs [102].

The thickness of the cleaved slates depends upon many circumstances, such as the quality of the rock, the size of slate required, and the purpose for which it is to be used. The average thickness of a roofing tile of the best kinds of Welsh slate is about one-sixth of an inch. The slates are afterwards trimmed to size, either by hand, in which case they are cut between a fixed sharp edge and a movable knife acting on the principle of a printer's guillotine (see Pl. 6), or by means of machine-driven rotating knives (see Pl. 7).

Before the introduction of sawing machines, the quarried blocks were divided into smaller blocks by continuing the process of " pillaring " until slabs a little larger than the required slate had been obtained.

The natural moisture present in freshly quarried slate materially adds to its flexibility and to the ease with which it may be cleaved. It is, therefore, necessary that the blocks should not be allowed to become dry before they are split, and in dry weather, if they are not immediately sent to the dressing sheds, the blocks are kept watered, especially in the case of slate obtained from underground workings.

The bibliography on page 64 contains a list of works in which the quarrying and preparation of slate is described, but the process must be seen to be properly appreciated: the owners of most of the slate quarries and mines in Wales offer facilities to visitors.

The uses of slate.—Although slate is usually thought of in connection with roofing tiles it has been used for a great variety of other purposes.

Its use for roofing tiles depends upon the ease with which it can be split into thin sheets of considerable tensile strength, for which, as we have already seen, the felted mass of interlocking mica crystals is largely responsible. Owing to the enormous pressure to which the rock has been subjected, spaces between individual particles are almost non-existent, and the best Welsh slate absorbs less than one six-thousandth of its weight of water: consequently, it is practically impervious to water, and on that account is not liable to be spoilt by

PLATE 5.—Dividing blocks of slate in the quarry, Penrhyn.

frost after being placed on a roof. It is also incombustible and a poor conductor of heat. Consisting, as it does, largely of mica and quartz, most kinds of slate are incorrodible, unless they contain an excessive amount of lime, and they resist, to a remarkable extent, the action of acids which are present in rain water, especially in that of large towns. Slates from North Wales are found to be practically unaffected, even in towns like St. Helens where chemical works and glass works cause the air to be more than usually contaminated with corrosive gases.

Slate is frequently used as a building stone. In many parts of Wales entire buildings are constructed of slate blocks, usually derived from the gritty or poorly cleaved material discarded as unsuitable for roofing slates. It is also used for door posts, window sills, and steps, and in slate districts is a frequent substitute for both wood and stone, often being the commonest material used for boundary walls and fences. The Devonian slates of Devon and Cornwall are extensively used for building purposes, especially near the granite masses, where the slate has been hardened.

Slate is useful for billiard tables and skin dressers' tables on account of the ease with which it can be sawn into slabs of considerable size, of uniform grain, and with no tendency to shrink or to warp. It is especially suitable for electrical switchboards because it is a poor conductor of electricity; for this purpose a slate free from pyrites is selected.

Because it is practically inert and incorrodible, slate is used for constructing vats to contain acids, and for such things as cisterns, dairy tables, and laboratory tables. Enamelled slate slabs are a frequent substitute for marble, in mantel-pieces and wash-stands.

The slabs are prepared by sawing and planing the blocks received from the quarry. Some of those required for switchboards may be as large as 12 feet by 6 feet. One of the largest slabs ever prepared (20 feet by 10 feet) was exhibited by the Llangollen Slate Company, at the International Exhibition in 1862.

As may be gathered from the enormous heaps of rubbish to be seen in a slate quarry district, the roof tiles and slabs sent away represent only a small proportion of the material actually quarried, and until recent years the waste slate was regarded as entirely useless. During the past ten years attempts which have been made to utilize this material have met with some measure of success. The slate waste is crushed and ground until it is in the condition of a fine powder which is useful for a variety of purposes. It is used (on account of its

power of absorbing grease) as a substitute for Fuller's Earth ; as a " filler " in the manufacture of coarse rubber wares such as tyres, mats and " rubber " heels ; and in asphalt paving material, abrasive soaps, paint, distemper and disinfecting powders. When entirely free from gritty material it is used in making polishing powder, toilet powder, and tooth powder.

Of interest in connection with slate powder is the discovery that it is capable of destroying the active properties of toxins such as that of diphtheria. To this may be attributed the noticeable rarity of sickness and of septic wounds amongst the workers in slate quarries [104].

There are many other uses to which slate waste can be put, and the consumption will probably increase, but under the most favourable of circumstances it is not likely that the demand will ever exceed the supply.

At one time, the smoother varieties of slate were in demand for writing slates, and in the early part of the last century there was an important factory for their manufacture at Port Penrhyn. The process was thus described by a contemporary writer [82, p. 233] :—" The rude slates from the mines are first reduced to shape and size by a small edged tool, similar to a plaisterer's hatchet ; they are then taken to the scraper, who, with a small piece of thin steel, takes off the imperfect laminae, and reduces the surface to a level : they are passed into other hands, who grind them with a flat stone ; afterwards polished by the actions of water and slate-powder ; and being stained with a black water-colour and framed, are piled up in grosses for exportation. They are distinguished into two sizes, large and small, price of the large, £5 per gross, and the small, £2 6s. 0d. ditto. To such a degree of proficiency have the Welsh arrived in the manufacture of this article, that they are able to undersell the Dutch, while the quality is much better." The use of slate for this purpose has, however, steadily declined in recent years.

Reference has already been made to the preparation of the pencils which were used for writing upon slate.

SLATE AND AGRICULTURE

Although similar in chemical composition to clay, slate reacts differently to the processes of denudation, owing to the mineralogical changes which its materials have undergone.

Clay weathers readily, forming low grass-covered hills and broad valleys. The soil to which it gives rise depends entirely upon the material from which the clay has been derived, and

as clays are very variable in composition the soils they yield are equally variable, but in general they are either naturally fertile or are capable of being made so. Slate, on the other hand weathers slowly, because mica, one of its most abundant ingredients, is a very stable mineral, and it tends to give rise to hilly or mountainous scenery. Owing to the well defined planes of weakness arising from cleavage and jointing, frost action tends to shatter the rock and gives rise to loose debris which slips down and forms screes flanking the lower parts of the hills, and these, in consequence, have smooth, even slopes. The higher parts have steeper slopes and frequently form jagged ridges, because the regular inclination of the cleavage planes causes projecting fragments to resemble the teeth of a saw.

In districts which, like North Wales, were occupied by ice sheets and glaciers during the Ice Age, the typical features of slate scenery are frequently replaced by the smooth rounded outlines characteristic of a glaciated district.

Not only does slate weather slowly, but it yields a thin and infertile soil, consisting of clay almost devoid of lime or useful soluble salts. Such soils are usually wet, because slate is practically impervious to water, which can only pass underground where there are joints or other open fissures. Poorly cleaved slates associated with sandy beds yield lighter soils, and generally speaking, the better the slate from a commercial standpoint, the poorer the soil which it yields.

THE HISTORY OF THE SLATE INDUSTRY IN WALES

The history of the slate industry in Wales has yet to be compiled. It is not possible in the space here available to give more than a brief account of this interesting subject, and for detailed information concerning the development of the industry in the various slate regions of the Principality the reader is referred to the works enumerated in the bibliography on page 63.

As an important industry in Wales, slate quarrying dates from the closing years of the eighteenth century, but there is ample evidence that slate has been used, intermittently, since the time of the Roman occupation. The purple slates of the Bethesda-Nantlle area were used in the Roman buildings at Segontium, near Carnarvon, where thick slabs were used for flooring and thin sheets as roofing tiles. Referring to these

slates, Dr. E. Greenly says that those used were not the best varieties, " probably because the finest beds tend to weather into smooth slopes, whereas the sandy beds are apt to outcrop in little ridges and thus be much more conspicuous " [103, p. 102].

The slate-yielding Silurian rocks of Denbighshire, already described, were also known to the Romans, because slabs with the characteristic fossils were used in the Roman fort at Caer Llugwy, near Capel Curig [73, p. 205].

One of the earliest written records concerning Welsh slates dates from 1399, if reliance may be placed upon a poem said to have been written at the time of the visit of Richard II. to Conway. The lines in question, which came from the pen of a French nobleman named Creton, have been thus translated :—

" So rode the King, without making noise,
That at Conway, where there is much slate
On the houses, he arrived, with scarce a pause
At break of day."—[93, p. 201].

The slate may have come from Penmachno or Dolwyddelan (where some of the quarries are known to be very old) because Conway would be the natural outlet for quarries in those regions. From Williams' " History of Aberconwy " we learn that in 1835 the slates were " brought to Trefriw in carts, and thence to Aberconwy in sailing boats, where they are put into large vessels, and exported to different parts of the kingdom " [84, p. 87]. That author anticipated considerable development of the town's trade, for he wrote :—" The opening of the slate quarries in the Carnarvonshire hills is also of great advantage, and this branch of commerce is gradually increasing." To some extent his expectations were realised, because in 1858, 27,000 tons of roofing slates and slabs were exported from Conway [53, p. 48]. With such a long and tedious journey, however, the slates could not compete with those from quarries more favourably situated, and the industry steadily declined until in 1876 the total output was only 6,000 tons. In recent years only a few small quarries have been worked, and those not continuously.

The Cilgwyn Quarry in the Nantlle district has been claimed as one of the oldest in Wales, and it is said that when Edward I. visited the copper mines at Drwys-y-Coed, the house in Nantlle in which he stayed was roofed with slates obtained from it. After a long period of idleness the quarry was re-opened at the close of the eighteenth century.

There were small quarries in the Ogwen Valley, Carnarvonshire, in the sixteenth century, for in 1580 Sion Tudor, a bard,

requested the Dean of Bangor to send him a load of slates from the Caehir quarry. The order was in the form of a poem, and explained that the writer was living in a thatched house, the roof of which afforded indifferent shelter in bad weather. He asked for 3,000 slates to be sent to Aber-ogwen, whence a ship was to convey them to Rhyl [90, p. 71].

Slate was being worked in the south of Merionethshire at about the same period, because an Elizabethan manor house at Aberllefenni was roofed with that material.

Leland, writing in the time of Henry VIII, describes the houses in Oswestry as having roofs of slate [91, p. 75]; it probably came from Llangynog or from Glyn Ceiriog, where the nearest quarries are likely to have been situated. The Rhiwarth quarry at Llangynog is known to have been worked for at least two centuries, while houses built in 1758 were roofed with slates from what is now the Penarth Quarry, near Corwen [97, p. 70].

In Pembrokeshire, also, there is evidence of the early use of slate, for material from the Gilfach Quarry in the Prescelly district was used in local thirteenth century buildings.

From Owen's "Description of Penbrookshire" we learn that at the end of the sixteenth century there was considerable trade in each of the three kinds of slate found in the country—the dark blue and black slates of the north, the grey slates of Prescelly, and the red "slates" or flags of the Old Red Sandstone. Owen was one of the earliest writers in this country to pay attention to the distribution of rocks, and his account of the geological features of Pembrokeshire is remarkably accurate. He observed that, in the slates, the cleavage planes dipped towards the north, or as he put it "in the quarrey it is found to lye in great flakes alwaies leaninge to the South: so that you must begine the quarrey from the north so shall you have the backe of the Quarrey towardes you." Concerning the use of the rock, he says:—"This stone being digged in the quarrey is cloven by Iron bars to the thickenes of a foot or halffe a foot, and in length and breadth iij or iiij foote, and so caried for walling stones; and for tyle, they cleave the same to what thinnes they thinke best, and so the self same stone and quarrey serveth to beginne and end the house" [74, p. 82].

Up to the middle of the eighteenth century the use of slate was sporadic and almost confined to the immediate neighbourhood of the quarries, but its useful properties were becoming more widely known, and there was a growing demand for Welsh slate in Ireland and in Liverpool. The latter half of the century saw old quarries resuscitated, small workings extended, and new ones commenced in every slate district.

At this time, Cae Braich-y-Cafn, the site of the present Penrhyn quarry, was dotted with small workings let to local men at a rental of one or two pounds each per annum, but in 1765, Richard Pennant (afterwards Lord Penrhyn) came into possession of the estate, and when the men's leases expired he commenced operations on a larger scale by starting what is now the Penrhyn quarry : the production rose from 1,800 tons per annum in 1780, to 20,000 tons in 1800. Until about 1780 the slates were carried on horse back to Aber-ogwen at the mouth of the River Ogwen, but the erection of a harbour at the mouth of the Cegin, a mile further west, made Port Penrhyn, Bangor, the outlet for the Bethesda slates.

Pennant records that during the closing years of the eighteenth century one hundred and three broad-wheeled carts were constantly employed in conveying slates to Bangor. In 1800 a horse tramroad was laid down, and since steam locomotives were introduced in 1874, the development of the quarry has continued, until it is now an immense horse shoe-shaped cavity in the mountain, and is one of the largest man-made excavations in the world.

It is almost impossible to describe this immense quarry, or rather collection of quarries, but the following account, which appeared in the " Mining Journal " in 1869 is worth quoting :— " The works are carried on both above and below the level of the original surface. The latter works are first reached. You stand on the brink of an open pit, with irregular sides, jagged with projections of slate rock. Above you and in front rise successive scarpings of the mountain side. The horizontal lines which, at a distance, appear to stretch like cobwebs at even intervals across the upper workings, are now discovered to be platforms, running from end to end, each forming the base of a separate quarry, along which is a tramway, on whose lines horses and trucks are visible. Between these lines, on the vertical face of the rugged rock, men work suspended, projected by ropes slung from the platform above, detaching blocks of slate rock, which fall or slide on to the platform below, and are then removed to the wings, where the slate blocks are selected, and the rubble tilted over " [46].

The history of the Dinorwic quarry at Llanberis is similar. From a series of small, separately worked openings in the mountain-side, it has become, in the hands of the Assheton Smiths and later owners, a great quarry rising in step-like terraces for 1,800 feet above the waters of Llyn Peris. Like those of Bethesda, the Dinorwic slates were originally sent to the sea ports in carts, but these were replaced by horse drawn trams, and subsequently by steam locomotives.

W. Bingley, who toured the district in 1800, refers to the primitive means then employed in bringing the slates down from the workings, some of which were situated high up on the mountain. At Llanberis, they were carried in carts with one horse in front and another behind to prevent the cart moving too quickly down the steep slope, and a still more hazardous method in use at Llangynog (Merionethshire) is thus described in Aikin's "Journal of a Tour Through North Wales," 1797 :— "The vehicle in which they are conveyed is a small sledge that will contain three or four cwt. of slates : on the fore part of the sledge is fastened by both ends a short rope. When loaded, it is drawn to the edge of the declivity ; a man places himself before it, with his face towards the sledge and the rope round his shoulders, then grasping the sledge with his hands, and raising his feet from the ground, the load together with the conductor begins to descend along a narrow winding path, down the scarped, almost perpendicular, side of the mountain. The motion, though moderate at first, accelerates very speedily ; and the business of the conductor is to govern as well as he can the increasing velocity, by striking the ground with his feet, and by opposing them to the projecting points of the rock, to retain the carriage in the proper path ; the least inattention or want of dexterity is certain destruction ; and yet does this man every day hazard his life four or five times, for the trifling pittance of about twopence a journey ! "

The quarries at Dolwyddelan and Penmachno have already been referred to, but no slates appear to have been worked in the immediate neighbourhood of Ffestiniog until about 1765, when some men from the Cilgwyn Quarry started the Diphwys (subsequently called Diphwys-Casson) Quarry.

Several once-famous quarries in this district were opened during the first few years of the last century, and many of the more important quarries or mines which are still being worked, were commenced between 1850 and 1880. Originally the slates were taken on pony back to Congl-y-wal and from there to the river side at Maentwrog by cart, completing their journey to Traeth Bach in barges.

In 1821 the construction of a harbour for the shipment of the slates from the Ffestiniog district led to the rise of the town of Portmadoc, to which a horse tramway from the quarries was constructed in 1833, making use of the embankment, built by Mr. W. A. Maddocks, to reclaim part of the marsh-land of the Glaslyn estuary. In 1873 steam locomotives were introduced on the construction of the now famous narrow-gauge mountain railway between Blaenau Ffestiniog and Portmadoc.

Coincident with the development of the quarries has been the formation of villages, often named after the chapels about which they have grown (Ebenezer, Bethesda, and Bethania); and towns of considerable importance have sprung up in connection with the harbours from which the slates were shipped. These have already been referred to.

Much interesting information concerning the early history of many well known slate quarries is to be found in the numerous "Tours in Wales" written at the commencement of the last century, and enumerated in the bibliography. D. C. Davies in his "Treatise on Slate and Slate Quarrying" describes the methods used in the slate quarries of Wales about fifty years ago, and gives particulars as to the cost of working and the prices then obtained for the slates.

Originally the roofing slates from any one quarry were small and all of approximately the same size—about eleven inches by five and a half. Between 1730 and 1740 larger sizes were introduced in the Penrhyn quarry district. Slates of the old sizes were then called "singles," and those of the new size (about thirteen inches by seven) were "doubles." During General Warburton's ownership (just prior to 1765) other sizes were introduced; these were called ladies, countesses, duchesses, princesses and empresses. The last mentioned were the largest, being about twenty-six inches by sixteen inches.

Many different sizes are still made at the present time, because, for no apparent reason, a size which is popular in one district cannot be sold in another. Twenty inches by ten is the size most commonly used in the south of England, smaller sizes being favoured in Midland towns. In Lancashire and Scotland the demand is for much thicker slates than would be accepted in many other districts, while in parts of Ireland particularly large slates are used—twenty-four inches by twelve in the eastern districts, and thirty-six inches by twenty-four in Galway [100].

Formerly, much larger quantities of slate were exported than is now the case, but as other countries have been opened up and their natural resources developed, local slate deposits have been utilised, because, although in most cases vastly inferior to those of Wales, they do not involve costly transport.

At the present time about sixty slate mines and slate quarries are being worked in Wales, but there are great numbers of disused quarries scattered throughout the areas where slate occurs. Many of these never passed beyond the experimental stage because the slates may have been too thick, too soft, or insufficiently durable, but in other cases although

slates of excellent quality were to be obtained, inaccessibility and difficulties of transport prevented their development.

The extension of railways played an important part in the rise of the slate trade in North Wales, and also in determining the location of the present centres of the industry.

As long as the slates were carried on horseback or by cart, no one district had any special advantage over another, but during the latter half of the last century certain areas, especially those where the best slates occur in the largest quantity, were brought within easy reach of the sea by means of railways.

It will be seen on examining a map, that most of the branch railways in North Wales run through or from a slate quarry centre—for example, Bethesda to Bangor, Llanberis to Carnarvon, South Snowdon and Rhyd-ddu to Carnarvon, Blaenau Ffestiniog to Portmadoc, Abergynolwyn to Towyn, Corris to Machynlleth, Dinas Mawddwy to Machynlleth, Llangynog to Oswestry, Glyn Ceiriog to Chirk. Other areas where the industry either failed to develop or has declined, are mostly those which are still unserved by railways; for example, about sixty years ago some of the quarries in the Llanfihangel-y-Pennant valley, south Carnarvonshire, were considered as very promising, but the slates were conveyed in carts over the flanks of Y Garn to Rhyd-ddu, and thence to Carnarvon. The valley has not yet been penetrated by the railway, and the quarries, unable to compete with others now favourably situated, have passed into disuse.*

FISSILE ROCKS OTHER THAN SLATE

It has already been shown that some rocks can be split into sheets corresponding to the original layers, or beds, of which they were formed, and occasionally the sheets so produced have considerable tensile strength: such "stone tiles" were used for roofing long before true slates came into general use.

Shales provide some of the best examples of fissility among rocks that are not slate, but the layers into which they split are never sufficiently strong to be of any particular use. Certain sandstones and limestones, when thinly bedded or "flaggy" as it is called, yield sheets suitable for roofing.

It is usually an abundance of mica† flakes that causes a

* Since these words were written (Dec. 1924), some of the quarries in the Pennant district have been re-opened.

† These are mica particles originally present in the rock; they are not the result of subsequent alteration like the minute mica crystals in true slates.

sandstone to split into thin sheets, and in such cases the surfaces are often spangled and shining.

The following are examples of the use, as roof tiles, of fissile rocks which are not true slates, but almost everywhere they have now given place to the thinner slates.

Certain highly micaceous sandstones in the Silurian (Ludlow) strata at Cilmaenllwyd, between 5 or 6 miles north of Ammanford, were at one time quarried for " tile-stones." Two beds were suitable for the purpose ; one was from four to ten feet in thickness, and the other from twelve to thirty feet, with pebbly sandstone between them. The strata at this place are vertical, so that the quarries took the form of trenches, ten or fifteen feet wide with straight sides. The rock was split into sheets about half an inch thick, and the finished tiles were small and heavy, but of pleasing appearance : each was kept in place on the roof by means of a wooden peg passed through a hole pierced for the purpose. Certain mudstones of Silurian age which yield slabs or flagstones have already been referred to on page 29.

Flaggy sandstones in the Old Red Sandstone formation have also been quarried for roof tiles at various places along the northern margin of the South Wales Coalfield, and in the Brecknock Beacons.

An excellent example of the use of thick sandy flags for roofing purposes is to be seen in an old barn at the farm, Y Gaer, near Brecon. Owing to the thickness, and consequently the weight, of the material, the roof had to be more highly pitched (that is more steeply inclined), and more heavily timbered when thick tiles were used, than is the case in modern buildings with slate roofs.

Thinly bedded micaceous sandstones in the Carboniferous formation have also been used for roofing purposes, particularly in Yorkshire, where similar but thicker beds constitute the " Yorkshire flags," used as paving stones.

The so-called " Stonesfield Slate " and " Collyweston Slate " are well known examples of stone tiles. " Stonesfield Slate " takes its name from the village of Stonesfield near Blenheim (Oxon.), and comes from a bed of impure micaceous sandstone about two feet thick, in the " Great Oolite " limestone series [6, p. 321].

" Collyweston Slate " takes its name from Collyweston in Northamptonshire, and is a similar rock occurring in the " Inferior Oolite " limestone series. Here, the " slate " bed is anything from six inches to eighteen inches in thickness, and is obtained from underground workings during the winter months ; the blocks are kept wet until they have been exposed to frost, after which they can be split in the direction of the bedding, and trimmed into roof tiles about eighteen inches long, twelve inches wide, and half an inch or more thick [2].

Roofing tiles have been obtained from many other fissile rocks, but they are almost unknown outside the districts where they occur. " Duston slate " from Duston, Northamptonshire, is similar to that of Stonesfield. Roof tiles have been obtained from the " Slatt Beds," which are thinly bedded limestones in the Lower Purbeck Beds near Weymouth, and from the " Horsham Stone " in the Wealden Beds of Sussex.

Many of the oldest (Pre-Cambrian) rocks of Scotland have passed beyond the condition of slates, and they are now completely crystalline mica-schists, but some of those in which the mica runs in very regular layers have been split and used for roof tiles, as for example, in Iona Cathedral.

One of the most remarkable of fissile rocks occurs in the Auvergne district of France, where a volcanic rock known as phonolite is affected by a system of closely arranged, parallel joints, which have made possible its conversion into roof tiles.

Acknowledgments.—In conclusion, the assistance which the owners and managers of slate quarries and mines in all parts of Wales have given in the accumulation of the material used in the preparation of the Museum's slate exhibit, is gratefully acknowledged. Specimens have been presented, and facilities for collecting granted with the utmost readiness, wherever they have been sought, and while the source of all the slate specimens in the Museum is acknowledged on the labels which accompany them, in this pamphlet thanks is tendered to the industry as a whole, because many quarries would not be represented in a list of those from which specimens have been received, only because their owners have not yet been approached.

Owing to the short time which has elapsed since the Museum commenced its activities, some districts are as yet inadequately represented, but it is hoped that before long the National collection will contain a complete and permanent record of the slates of Wales, to which the words of Carew (1602) might well be applied—" In substance thinne, in colour faire, in waight light, in lasting long."

APPENDIX I

Table of Strata, indicating the distribution of slate in Wales. The relative thickness of the strata in each geological formation is indicated by the space allotted to it.

Names Given to the Divisions of Geological Time.		Levels at which Cleaved Rocks and Workable Slates occur in Wales.	Other Important Slate Areas.
Cainozoic	Tertiary & Recent		
Mesozoic	Cretaceous	No cleavage has been developed in Cainozoic or Mesozoic rocks in Great Britain.	Fissile rocks (not true slates) occur among Jurassic strata.
	Jurassic (including Lias)		
	Triassic		
Palaeozoic	Permian		
	Carboniferous		
	Devonian		Delabole (Cornwall). Westphalia, Belgium.
	Silurian	Llangollen. Corwen, Glyn Ceiriog. Esgairgeiliog.	Lake District.
	Ordovician	Abergynolwyn, Corris. Llangynog Ffestiniog district. Pembrokeshire.	Lake District (Green slates). Lake District (Skiddaw Slate).
	Cambrian	Tremadoc, Arthog, Fairbourne. Penrhyn, Dinorwic, Nantlle.	Slates occur among the Ordovician and Cambrian strata of U.S.A.
Archaean	* Pre-Cambrian	The Pre-Cambrian rocks in Wales are too much altered and crumpled to yield workable slates.	Charnwood Forest (Leicestershire). Ballachulish (Scotland).

* The relative length of the Pre-Cambrian period cannot be accurately estimated, as the base of the formation has not been found. It was probably as long as all the later periods put together.

The names in the first two columns are those given to the periods into which geological time has been divided, and to the rocks formed during each of those periods. Palaeozoic, Mesozoic, and Cainozoic, imply respectively, "ancient life," "middle life," and "recent life," and are used to designate three of the four major periods of earth-history. During the Palaeozoic era the animals and plants were almost entirely of kinds now extinct; the Cainozoic era was characterised by the prevalence of animals and plants closely allied to those now living, while the life of the Mesozoic era was intermediate in character between that of the other two. The earliest period was sometimes known as Azoic, because it was formerly supposed that it was entirely without life, but, although no fossils have been found in the oldest rocks in this country, it is quite certain that living things had already appeared on the earth, because the nature and variety of the fossils found in the oldest fossil-bearing strata indicate a very long period of previous development. On this account the term "Archaean" (meaning ancient) is now generally used to designate all the rocks older than the Cambrian. They are also called Pre-Cambrian.

The names given to the smaller sub-divisions of geological time and to the rocks formed during them, refer in some cases to the district in which the rocks were first studied or are very well displayed; for example, the Cambrian strata are well developed in Wales; the Ordovician and Silurian in those parts of Wales and the border counties occupied by the ancient tribes of the Ordovices and the Silures respectively; the Devonian, in Devonshire; the Permian in the Russian province of Perm; and the Jurassic in the Jura Mountain region of France.

Some of the names allude to the character of the rocks. Carboniferous (carbon bearing) and Cretaceous (chalk bearing) refer to the presence of coal and of chalk in the formations enumerated.

In the table of strata on page 54, the existence of cleavage in the rocks of any period is indicated by fine inclined lines, which are closer together in cases where the cleavage has resulted in the formation of commercially important slates.

It will be noticed that, in Wales, all the workable slates occur among Lower Palaeozoic rocks.

APPENDIX II

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PLATE 6.—SPLITTING AND HAND-TRIMMING SLATE.

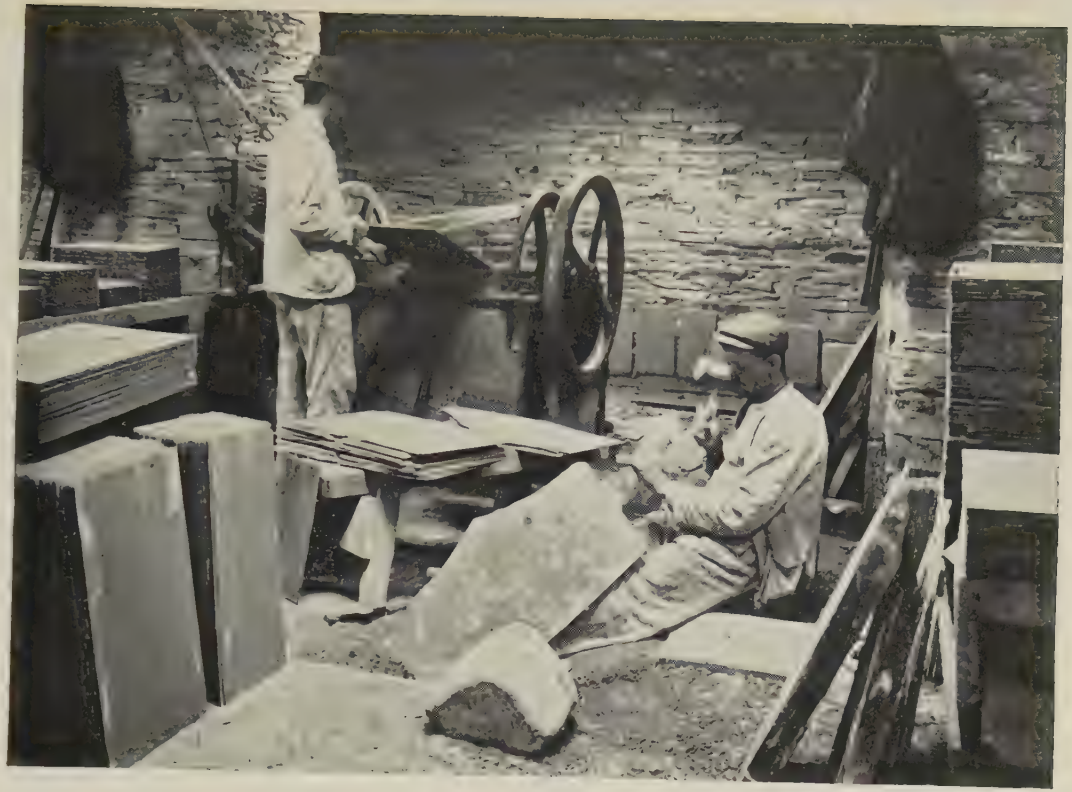

PLATE 7.—Splitting and machine-trimming slate, Maen Offeren Quarry.

PLATE 8.—Machines for sawing slate, Maen Offeren Quarry.